Judgment of speed in a traffic situation

An Experimental Study

by Ingemar Norling

ALMQVIST & WIKSELL
STOCKHOLM
GÖTEBORG · UPPSALA

JUDGMENT OF SPEED IN A TRAFFIC SITUATION

An Experimental Study

INAUGURAL DISSERTATION

By INGEMAR NORLING
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PREFACE

This investigation was made at the Institute of Psychology, University of Uppsala. Professor Gunnar Johansson, the Head of the Institute, has followed my work from the very beginning. I owe him a deep debt of gratitude for his encouragement and valuable advice.

The study is part of a larger investigation project in which the others taking part are Docent Mats Björkman and Fil. kand. Berndt Brehmer. I take sole responsibility for the contents of the present report. Björkman has participated in discussions in conjunction with the research work, and has also gone through my manuscript. Brehmer, too, has taken part in these discussions and acted as leader of experiments and helped me in the processing of the data. I am exceedingly grateful to them for their very generous help.

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Uppsala, November 1963

INGEMAR NORLING

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CHAPTER 1

INTRODUCTION

It is usual in traffic research and traffic planning to discriminate between three types of problems; those referring to drivers, those referring to vehicles, and those concerned with traffic environments (Suchman & Scherzer, 1960). Studies of accident statistics which have taken this discrimination into account show that drivers are responsible for a very large proportion of all accidents (Conger, 1961). Much scientific research on the behaviour of drivers in traffic has been commenced during recent years.

The main purpose of the present study is to investigate experimentally how correctly the speeds of motor vehicles can be judged in traffic. To link up the present study with other research being performed from the aspect of drivers in traffic, point 1.1 below gives a brief survey of the current situation in research. The rest of the chapter deals with choice of problems, experimental situations and certain fundamental questions of methods.

1.1. Brief survey of current behavioural traffic research within the driver sector

To make the account more surveyable, the problems have been divided into two types; those of a practical nature, and more theoretical ones. Such a division must, of course, be a rough one only, for no clear line of demarcation can be drawn between these two types of problem.

1.1.1. *Practical problems and types of measures adopted in applied research*

As a basis of discussion, a group of drivers, representative of the whole population of drivers, may be imagined. The level of skill is assumed to give a normally distributed performance continuum. A division into three types of measures adopted can then be made, and the problems will be found to fall within these groups.

Type 1: The general aim of this type is to raise the level of the whole or part of the performance distribution. The problems often pertain to methods in the spheres of training, propaganda, legislation and the like. As concrete examples may be mentioned courses in winter driving, propaganda campaigns referring to night driving, and more severe sentences on people driving while under the influence of alcohol. Tests in driving prior to a person being granted a driving license belong to this type, too. Although measures of this type are considered of great importance, not much is known of their effect. This has been stressed by Barnes & Flanigan (1958) and others. Conger (1961) states that it is even difficult to demonstrate the value of more comprehensive lessons for drivers.

Type 2: The purpose of this type of measure is to make a selection within the performance continuum. The selection made in driving tests belongs in principle to this type of measure. Selection in the upper part of the performance continuum is applied in the choice of professional drivers in, for example, the transport industry (McFarland, 1954; Häkkinen, 1957).

Several investigations have shown that it is not easy to make this type of measure effective. Olwéus (1958) has demonstrated that driving tests are seriously lacking in reliability, while McFarland (1954) maintains that knowledge of the efficiency of the selection on higher performance levels is limited.

Type 3: The general aim here is to improve the behaviour of drivers in traffic by making cars and traffic situations easier to manage. Thus this type is concerned with human engineering. More legible traffic signs, skid-proof tyres, level-crossing gates, polarized light and marking stretches on which overtaking is prohibited are a few concrete examples.

Both research and the application of the results have been rare in this sphere. Hafstad (1957) has pointed out that the main part of the work performed in traffic engineering has no relation to human factors research. According to Hafstad, measures of this type are more neglected in highway traffic than in the communications industry and the aircraft industry.

1.1.2. *Assessment of the efficiency of the types of measures*

Measurements made in applied research in this sphere are usually compared with undifferentiated combined measures of safety in traffic, e.g. frequency of accidents. It has been shown consistently that the relationship between, for example, personality measurements and accident data is low for normal groups of drivers (McFarland, 1955; Conger, 1961). The essential problem, however, is not how measurements and changes are to be included in the types of measures mentioned above, but how to gauge scientifically and acceptably (criterion, parallelly ordered measures) changes in safety in traffic, e.g. lower frequency of accidents (Conger, 1961; Jacobs, 1961).

Measurements of the latter type contain a number of important variables that are most often impossible to check, e.g. basic frequency (number of miles driven, distribution of types of vehicles etc.) and probability of exposure (is the degree of difficulty in traffic situations (p-value) normally distributed over groups of drivers? etc.). Suchman & Scherzer (1960) hold the view that the great variable range of the functional measures,

and difficulties with content validity and reliability have led to only broad experiments of the type "program testing", e.g. trials with speed limits, being given an acceptable form in so far as validity regarding content is concerned. Other examples are the great projects with multi-variable studies of the type epidemiological analysis in medical research (Irby & Jacobs, 1960; Kraft, 1959; Suchman & Scherzer, 1960). Thus opportunities of testing the efficiency of the types of measure are strictly limited. To correlate "narrow" variables of the type visual acuity with frequency of accidents is probably of little value. It is even difficult, as has been mentioned above, to prove the value of more comprehensive lessons in driving.

The combined functional measures can hardly be applied in restricted studies of the behaviour of drivers. Instead the use of simulators is becoming more and more common (Tarrants, 1960), or field experiments, i.e. methods with relatively great realism (Crawford, 1963). In this connection, prominent traffic researchers, among them McFarland (1959), maintain that simplification of the experimental situations should not be carried too far, but that they should, if possible, contain all three components—driver, vehicle and traffic situation. This view of research suggests a certain tendency to regard data from more specific laboratory experiments as irrelevant.

1.1.3. *Theoretical problems in driver oriented research*

As basis of division for theoretical problems in driver oriented research has been chosen that used in Report from the Williamsburg Conference, 1958, on traffic research (Special Report, 1958). In this report, research is classified according to the model input–organization–output.

Input is usually understood to mean the stimulus side of a

behaviour situation, e.g. what information is present in a traffic situation and how it is registered by a driver. The registration of traffic signs and signals, judgment of speeds of cars and similar elements belong, as external input, to this field.

The *organization* process is usually concerned with forms of behaviour within such regions as learning, ability, emotion and decision making. As examples of driver behaviour may be mentioned reckless driving, adaptation to winter roads and decisions referring to overtaking.

By *output* is usually meant the explicit response part of a driver's behaviour. It should therefore be concerned mainly with motor behaviour. Such actions as backing, taking corners and braking belong to this sphere.

The three spheres—input, organization and output—cannot, naturally, be regarded as regions of behaviour wholly independent of each other. They should rather be viewed as dependent parts of a process. When overtaking, for example, a judgment of the speeds of cars, and their positions in space must be made (input), after which a decision is made on the basis of this judgment—overtake or not—(organization), and finally the overtaking manoeuvre is made as a consequence of the decision (output).

This makes it difficult to keep the three spheres separate from each other. Part of the research on "organization" must take questions of output into consideration, e.g. the study of different training methods (Brody, 1961). The same problem appears when different research models are applied. Thus the organization sector is stressed in the decision-making approach, but at the same time it bases its reasoning of subjective–objective probability on input data on the subjective equivalents to the physical situation variables (Suchman & Scherzer, 1960). A model of this type hangs, so to say, in thin air if data is lacking on what information a driver gains from the stimuli and how he

uses it in different traffic situations to control the central physical events, e.g. changes in the position of his vehicle.

The distribution of research over the three spheres, input, organization, output, is uneven. It is said in the Special Report (1958) that the lack of data from the input and output spheres is great, and that relatively comprehensive but still insufficient research is being performed in the organization sector.

Research on the problems that can be classified as belonging to the input sphere is lacking in data on such elements of central behaviour as judging speeds and distances. But the study of such problems as, e.g. registration of traffic signals (Johansson & Backlund, 1961) and objects on the road in night driving (Johansson & Ottander, 1963) is going on. A demand for more research in the input sphere is found in many works. The lack of data has become a serious obstacle in the way of research depending on input data (Conger, 1961; Prisk & Brody, 1958; Suchman & Scherzer, 1960; Tarrants, 1960; Forbes, 1960).

The research being carried on in the organization sphere is dominated by problems of clinical and differential psychological orientation. Numbers of studies deal, for example, with personality variables and emotions relating to behaviour in traffic (Beamish & Malfetti, 1962; McFarland, 1954; Rommel, 1959; Suchman & Scherzer, 1960). On the other hand, the amount of research is more limited in such spheres as learning and decision making (Brody, 1961; Crawford, 1963; McFarland, 1959). There are great difficulties in the way of obtaining reliable results, since measurements of, for example, personality variables are usually related to traffic safety data of the type frequency of accidents. As mentioned earlier, such procedure leads to extremely great difficulties in methods.

There are only few studies in the output sphere. Investigations related to medical research, e.g. Hutchinson (1958) and Shaw

(1958), or to problems of training, Brody (1961), Suhr & Lauer (1961) and others, exist.

The question of why research in the input and output spheres is so limited is a serious one. The problem is probably connected with the dominant causal orientation that traffic research has had, and still has. If such specific input and output variables as judgment of speed, reaction time and steering are related to such combined measures as accident statistics, there is good reason to expect that there will not be any correlation owing to lack of content validity. Many investigations of this type have been made earlier, and the low relationships obtained have probably given an erroneous underestimation of the relevance of more specific research in the spheres of input and output.

It seems to me necessary that traffic research, especially in the spheres of input and output, is released from connection with combined measures of the type accident statistics. As mentioned above, a relatively great realism in the experimental situations is present when simulators and field experiments are used. Crawford (1963) has demonstrated good agreement between behaviour in field experiments and in practical driving in normal traffic situations. The technical development makes it possible to construct effective simulators, e.g. with television technique (Hutchinson et al., 1958).

It is naturally very important that data from these more realistic types of experiment are correlated to data from more specific laboratory experiments. In this way, an essential reinforcement of the empirical basis, and at the same time also connection to fundamental theories can be obtained.

1.2. Choice of problems

The main problem in the present study refers to a driver's judgments of the speeds of cars, a problem chiefly in the input sphere.

The choice of problem has been influenced partly by the experimental aims of our study group. Björkman, one of the team members, has made a series of experiments on drivers' predictions of meeting points between own and an oncoming car (Björkman, 1963). The present study is partly a continuation of these experiments.

1.3. Choice of experimental situation

I have chosen, on the background of the discussion in points 1.1.2–1.1.3 above, to work with *experiments in a field situation, including drivers, vehicles and traffic environments.* The experimental situation should be such that it is possible to control acceptably different variables, and easy to reproduce different partial experiments.

The situation is as follows from Fig. 1:1.

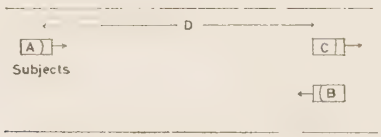

Fig. 1:1. Experimental situation.

The physical event in this traffic situation may be described by the variables distance (D) and time (T). The uniform speeds of the cars (V) may be expressed as $V = D/S$. Since it is not clear from the beginning which variables are primary in the driver's opinion, it seems simpler for the time being to work with the terms distance and speed, which are common in connection with traffic. Starting from Fig. 1.1 above and the variables distance and speed, the different S and R variables may be tabulated as follows:

Description of the physical variables included in the experimental situation.

D: Distance between A and B and A and C respectively
V_A: Speed of car with subjects (A)
V_B: Speed of oncoming car (B)
V_C: Speed of car (C) driving in front of and in same direction as A

Division into physical measures (capital letters) and subjective measures (small letters) gives:

List of the physical variables and their subjective equivalents.

Physical variables	V_A	V_B	V_C	D
Subjective variables	v_A	v_B	v_C	d

1.4. Simultaneous and predictive judgments

In the experimental situation, the subjects can make *simultaneous* judgments of one or several variables, or *predictive* judgments of events which include one or more variables. By simultaneous is meant that the items of S information are present at the same time, and that the judgment refers to events during exposure time. By predictive is meant that the items of S information are present at the same time, but that this information is to be used for a prediction of the development of the event. The simultaneous judgments should contain less processing and organization of the stimulus information than predictive judgments. The predictive judgments of meeting point are naturally based on input from several stimulus variables and a certain processing and organization of the stimuli. A correct judgment and combination of V_A, V_B and D are required for a veridical prediction of the meeting point between A and B.

1.5. Methods

From the starting-point of the physical variables on the experimental situation, the choice of methods will be obvious. The experiment with predictive judgments of e.g. meeting points implies that the subjects must localize a point on the road lying in front of them. This type of judgment gives a direct connection with *classical psychophysical methods* with determination of threshold values, systematic errors and areas of uncertainty.

When it is a question of simultaneous judgments of, for example, the speeds of cars, it becomes natural that the physical measures will be related to the subjective equivalents and the R–S functions thus obtained. Among the methods used in the present investigation are ratio estimation and magnitude estimation.

In the experiments where the stimulus range is so short that confusion occurs, a measure of the confusion in the form of percentile or z functions can be calculated. Magnitude estimation data can be used for these calculations (cf. Goude, 1962).

Direct scaling methods, e.g. magnitude and ratio estimations have been used to a certain extent earlier for the determination of subjective scales of speed.

Thus laboratory experiments have been made on the judgment of the motion of an object on the vertical plane e.g. by Ekman & Dahlbäck (1957) and Mashour (1963). The R–S functions obtained have the exponents 1.72 (Ekman–Dahlbäck) and 1.04 (Mashour).

Applied experiments with direct scaling methods have been made on the judgment of the speed of the own car (Borg, 1961; Rumar, 1962). The R–S functions obtained have the exponents 2.0 (Borg) and 1.0 (Rumar).

The more special questions of method will be discussed in connection with each experiment.

1.6. The concept of veridicality

The term veridicality is used to imply agreement between the subjective and physical variable. Several operational definitions of veridicality are possible.

The problem of veridicality in the direct scaling methods can be illustrated most simply by an example. Let it be assumed we wish to study v_A as a function of V_A, which has been given the values 20, 30, 40, 50 and 60 km/h. The oncoming car is used as standard stimulus (which implies that standard and variable occur together), and has, throughout the experiment, the constant speed of 40 km/h. The standard is given the value α in the instructions. For each speed of his own car, the subject must give a number which has the same relation to the standard α as that he experiences between the speeds of the cars.

The question of veridicality may have two aspects

1. How well does the subject's estimation fit the value α, when the cars are driven at the same speed?

2. If the absolute value which the subject assigns to $V_A = 40$, how well do v_A and V_A agree then?

Perfect veridicality, i.e. perfect agreement between subjective and physical variables implies a linear relation with slope = 1 and the y-intercept = 0. From the starting-point of the two aspects of veridicality mentioned above and the equation for the rectilinear line as a measure of perfect agreement between subjective and objective variable, four partial criteria can be formulated for the practical testing of the veridicality of the judgments.

1. Can a rectilinear line be adapted? ($R = a + bS$)
2. If so, is R_α then equal to α?
3. Is $a = 0$?
4. Is $b = R_\alpha/\alpha$?

The description of data has then been made so that rectilinear lines are adapted according to the method of least squares. But since there is reason to expect that the correlation will have an accelerated tendency (Stevens, 1957), power functions have been calculated. But they must, of course, be used with caution since the number of stimuli (V) is only five or six. The method used for calculation of power functions is described at the end of Appendix.

Criterion 2 has validity and interest, since the standard can be placed simultaneously on other cars. The four criteria are not independent except when $R_\alpha = \alpha$ and $a = 0$. Criterion 4 gives no new information. Criterion 1 is fundamental and independent. The others are all dependent on 1.

In the following experiments of judgment of speed, several variants of direct scaling are used. Ratio estimation and magnitude estimation with standard are used. In addition, as a complement, estimation in km/h with standard and estimation of distance driven in metres without standard are used. Owing to these differences between the methods, the criteria for meaningful testing vary in composition.

The testing of the veridicality of the experimental data in different methods will be according to the following table.

Applicable criteria for testing the veridicality of different variants of methods.

Criterion	Magnitude estimation	Ratio estimation	Metre estimation	km/h estimation
1. $R = a + bS$	×	×	×	×
2. $R_\alpha = \alpha$	×	–	–	×
3. $a = 0$	–	×	×	–
4. $b = R\alpha/\alpha$	×	–	–	×

1.7. The following chapters

In Chapter 2 follows an account of a series of experiments on the judgment of V_A, V_B and V_C. The account is so arranged that the different experiments referring to V_A are dealt with first (1a, 2a, 2b, 5a), then the experiments referring to V_B (1b, 3a, b, 4, 5b), and finally experiments referring to V_C (6, 7). The results from Chapter 2, subjective scales for V_A and V_B, are then combined in Chapter 3 with data from the experiment on the prediction of meeting point (Björkman, 1963) published earlier.

In Chapter 4 follows an experimental study of some stimulus problems, including angle of vision in the judgment of V_B and V_C (exps. 8, 9).

Chapter 5 gives a summary of the results.

Tables with data from each experiment are given in the Appendix.

CHAPTER 2

EXPERIMENTAL STUDIES OF JUDGMENT OF SPEED IN A MEETING SITUATION

2.1. Introduction

The purpose of Chapter 2 is to study with what degree of correctness a driver can assess the speed of his own car (A), the speed of a car approaching from the opposite direction (B), and that of one driving in front of and in the same direction as his own car. (C) The physical variables are the speed of the own car (V_A), the speed of the oncoming car (V_B) and the speed of the preceding car (V_C). Direct methods are used, e.g. ratio estimation and magnitude estimation. The reports of the different experiments are presented according to the table below.

Table of the different experiments

	Exp. no.	Type of judgment	Criterion of perfect veridicality
V_A	1 a	ratio estimation	1, 3
	2 a	magnitude estimation	1, 2, 4
	2 b	magnitude estimation	1, 2, 4
	5 a	distance driven in m without standard	1, 3
V_B	1 b	ratio estimation	1, 3
	3 a	magnitude estimation	1, 2, 4
	3 b	magnitude estimation	1, 2, 4
	4	km/h with standard	1, 2, 4
	5 b	distance driven in m without standard	1, 3
V_C	6	magnitude estimation	1, 2, 4
	7	km/h with standard	

Two general problems have been formulated

How veridically do drivers judge V_A, V_B and V_C?

In what way do drivers' judgments of V_A, V_B and V_C differ with reference to veridicality?

2.2. Experimental situation

The site used for the experiments was a reserve airfield with two runways, 715 m long and 32 m wide, at right angles to each other. The airfield has a rather rough asphalt surface, less smooth than an ordinary Swedish asphalt highway. The surface is also rather uneven, with pools of water in wet weather and dust from adjacent corn fields when the weather is dry and windy. A longer track, 1500 m long, was used in experiment 5 (V_C).

Distance (D) between motor-cars A and B during the exposure time has been determined at approximately 400 m. Pilot tests were made over the whole of the overtaking distance, with an initial speed of 60 km/h. The mean overtaking distances driven by different subjects over ten runs were for subject 1, 272 m, for subject 2, 172 m, and for subject 3, 174 m. The distances of the different subjects to the car before and after overtaking varied considerably. Subjects 2 and 3 overtook with a rather narrow margin. If the margin of safety, exposure time and tendencies towards greater distances at higher speeds than 60 km/h are also taken into consideration, 400 m seems to be a reasonable distance on which to base a discussion. The overtaking distances were measured by means of a specially constructed distance indicator connected to the ordinary distance indicator of the car.

The *speed* of the cars (V_A and V_B) can be varied up to a total of ($V_A + V_B$), about 120 km/h within the limits of the runways, with an average judgment distance of about 400 m. This also allowed a margin of about 50 m for variations of the starting-points, and for comfortable turning of the cars.

Acceleration was included in one phase of the experiment, namely up to the constant speed during the exposure time. Two Volvo Duetts, 60 h.p., engine B 16, were used. The acceleration curve was determined experimentally with the help of the specially constructed distance indicator. Maximal acceleration was used, for that is the easiest to keep constant. It also conforms with the acceleration usually applied in overtaking situations involving a meeting car. The drivers had had long experience of Volvo cars, and were trained to maintain constant acceleration and exposure speeds.

Starting system and exposure time

Each trial was started by the leader of the experiment (E) blinking his headlights three times. The time, 10 seconds after the start, when E said "Now" to the subject, was measured with a stop-watch. The exposure time was 5 seconds in all experiments.

Time-distance diagram illustrating the experimental section

The design of the experimental situation may be illustrated in principle by a time-distance diagram of experiment 3 b, which referred to magnitude estimation of V_B. The distance between cars A and B was 400 m in the middle of the exposure time (after 2.5 sec). During judgments, V_A was kept constant at 40 km/h, while the speed of V_B was varied within the range 20, 30, 40, 50 and 60 km/h.

A number of details of the experimental situation common to all the experiments can be illustrated by the time-distance diagram.

1. Speeds (V_A, V_B, V_C) were always constant during exposure time.

2. At different combinations of speeds the distance (D) between the cars was always the same at a certain point during

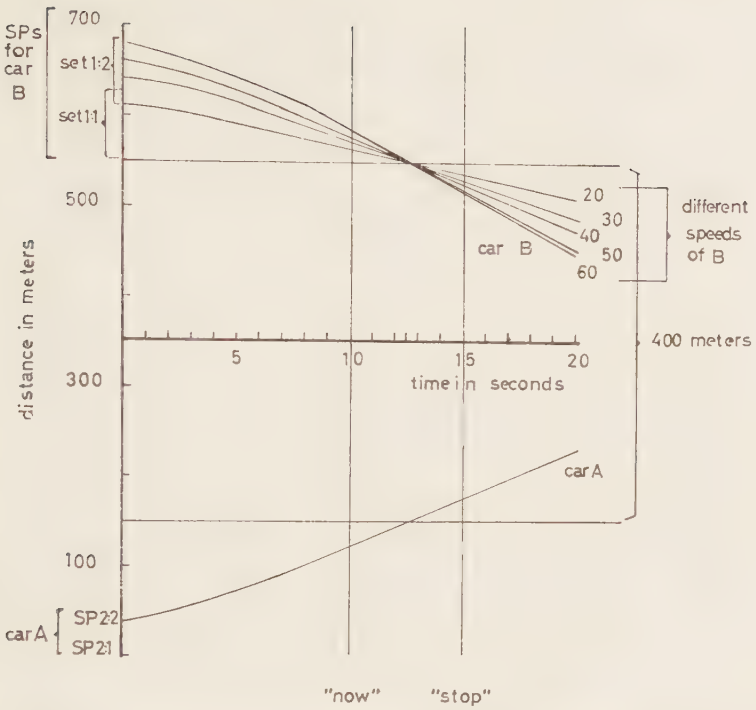

Fig. 2:1. Time distance diagram illustrating the experimental situation (exp. 3b).

exposure time. In experiments 1, 2a and 3a, D was kept constant at the beginning of the exposure time, but in the other experiments it was changed so that D was kept constant in the middle of the exposure time. In this way the unavoidable relation between speed and position was reduced to a minimum.

3. The highest relative speed permitted by the length of the runway was 120 km/h. For that reason the greatest speed in the speed variations was fixed at 60 km/h. In most of the experiments, the speeds 20, 30, 40, 50 and 60 km/h were used. The speed of 0 km/h was used in some experiments (4, 5 and 6).

4. The figure shows that the exposure time always began after 10 seconds. It is an obvious control measure to keep the interval

constant, but 10 seconds corresponds to the time taken at top acceleration to attain the highest speed of 60 km/h.

5. Exposure time was always 5 seconds. This interval was found suitable by a series of tests. The subjects were not allowed to see the car before and after exposure, so some time was spent at the beginning of exposure to fixate the car. None of the subjects thought the time too short.

6. Several series of starting-points (SP) were used (see Fig. 2:1) in order to vary position conditions. Four series are shown in the figure (ser. 1:1; 1:2; 2:1; 2:2). This means, for example, that the car with the subject (car A) for one and the same speed could start in series 1:1 and 1:2 at one end or in series 2:1 or 2:2 at the other end of the runway. Since the runway is 32 m wide, it could be employed so that the whole of this position system could be used along both edges. Then a maximum of eight conditions could be obtained for starting-points.

Subjects

With a few exceptions, men and women undergraduates aged 20 to 24 years, all holders of driving licenses, were employed as subjects. The population consisted of undergraduate students of psychology and other undergraduates who had applied to take part in the investigation for payment. Working as subjects in investigations is part of the course in psychology. It was practically impossible to make random selections from this population, for, among other things, the trials took a whole day for each subject, and it was extremely difficult to adapt trial times to lecture periods. On the other hand, the subjects were not systematically distributed over lecture days.

The subject was not allowed to drive the car, but sat beside the driver as an *observer*. This deviation from realistic conditions in ordinary driving was probably of little importance, since the

experiment treated especially the input phase. Also, using subjects as drivers would have given rise to a number of practical and methodological problems. The driver's task was a complicated one and demanded long training and exact knowledge of the conditions of the experiment. Knowledge of these, e.g. the speed of the car and starting-points would affect the judgments in a way very difficult to control and in a rather unrepresentative way from the aspect of the situation.

Description of the individual experiments and their results

When performing ratio estimation (exp. 1) and assessing distance driven in metres (exp. 5), the subjects made their judgments of A and B simultaneously. Since I have chosen to report experiments and results separately for V_A, V_B and V_C, the results of experiments 1 and 5 are given divided between V_A and V_B. The description of the experiment is given together with the account of experiments with V_A.

Figures with adapted power functions and rectilinear lines according to the method of least squares are given for each experiment. The equations are added to the figures. Tables for each experiment will be found in the Appendix in the order in which the experiments are described. No direct references are made to the Appendix in the accounts of the experiments.

2.3. Experiments on the judging of speed of (V_A) and distance driven by (D_A) own car

2.3.1. *Ratio estimation of speed of own car and that of the oncoming car (exp. 1)*

Ratio estimation was the first direct method experiment. This was because I wished to ascertain at an early stage whether the most demanding of the instructions among the direct rating methods worked satisfactorily. The fundamental assumption

behind the direct methods is that the subjects are able to obey the instructions. In addition it was of value to obtain scales for V_A and V_B at the same time with the same subjects and the same experimental conditions.

Problem: How veridically can observers in a car judge the speed of their own car in per cent of the speed of another?

Arrangement of the experiment

The speeds of car A (V_A) and car B (V_B) were 20, 30, 40, 50 and 60 km/h, which gave a matrix with 25 combinations. Each combination of speeds had a starting-point so that the cars simultaneously passed marks placed 400 m from each other. Each combination was used four times, each time in a randomly arranged block of 25 combinations. Two subjects at a time sat in each car, placed in the front and rear seats in ABBA order over blocks. The subjects changed cars after two blocks. There was a break of ten minutes between blocks 1 and 2, and between blocks 3 and 4. A pause of one hour separated block 2 from block 3.

The *exposure time* for the judgment from E's "Now" to "Stop" was 5 seconds. This exposure time, which was also used in the following experiments, was determined by pilot tests. An exposure time of 3 seconds should be ample, but since both fixation of car B and judgment were included in the exposure time, it was considered that 5 seconds would be a more suitable period. As soon as the reply had been written down, the slip of paper on which it was written was put away.

Subjects: Eight undergraduates, all holders of driving licenses, were employed as subjects.

Instructions: The subjects were told (1) to say which car was travelling the faster, and (2) to assess the lower speed in percentage of the higher. Five randomly selected combinations of

speeds were used for instruction and adaptation to the experimental situation. The subjects were reminded of the instructions in each block so that uncertainty and "up-and-down" effects would be avoided. The pilot tests showed that this was necessary. The subjects were not allowed to see the oncoming car until E said "Now", i.e. when the distance between the cars was 400 m.

Processing of data and result of experiment 1 a (V_A)

The matrix with 5 × 5 speeds gives 25 combinations of V_A/V_B. Each subject made four judgments of each combination, which makes 100 judgments per subject. Although the eight subjects were carefully instructed before the experiment, and were constantly reminded of the instructions during the whole experiment, two of them were unable to obey the instructions throughout the whole experiment. Now and then blocking clearly occurred, and the subjects reversed the direction of the ratio. Their values have not been included in the calculation of the scales for V_A and V_B.

Data from the six remaining subjects have been processed by a general method developed by Ekman (1960).

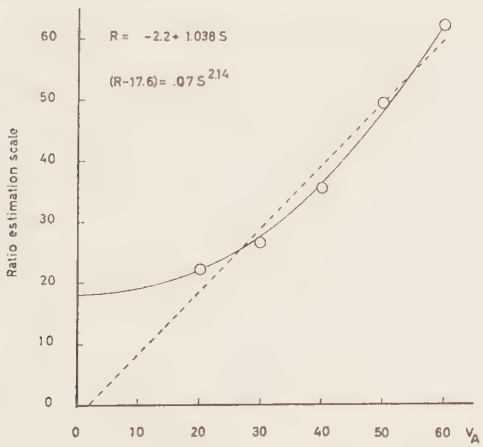

Fig. 2:2. v_A as a function of V_A, ratio estimation (exp. 1 a).

2.3.2 *Magnitude estimation of speed of own car with speed of oncoming car as standard* (*exp. 2*)

Problem: How veridically does the observer in a car judge the speed of own car, with speed of oncoming car as standard?

Arrangement of experiments (2a and 2b)

These magnitude estimation experiments had simpler instructions and experimental set-up than experiment 1. To avoid problems with errors of time in non-simultaneous judgments, B's speed was taken as standard. Only one standard, $V_B = 40$ km/h, was used. The first experiment, 2a, had a $D = 400$ m at "Now", and the second, 2b, had a $D = 400$ m at "Now" +2.5 seconds. Experiment 2b also had two series of starting-points with 50 m distance from each end of the runway. V_A was given the values 20, 30, 40, 50 and 60 km/h in blocks containing all these speeds in random order, while V_B was always 40 km/h during the exposure time, which was 5 seconds. The subject wrote each reply on a numbered slip of paper. E timed acceleration time and exposure time and gave the signals "Now" and "Stop". The experiment continued for ten blocks.

Instructions (2a and 2b)

The subjects were instructed to assess the speed of their own car (V_A) in relation to the speed of the oncoming car, which was constant and called "50". They were also given instructions on scaling: "If you assess V_A as half of V_B, write 25; if you consider that V_A is twice as fast as V_B, write 100. You may use any whole number you wish." A block with V_A-values in random order was used for training. The subjects were reminded at each block of the instructions in order to exclude uncertainty and "up-and-down" effects. Subjects were not allowed to see the oncoming car until E said "Now".

Data for experiment 2 a

Subjects: The subjects were two nursing students and one male undergraduate. All had driving licenses.

Processing of data and result

Geometric means were calculated for all judgments at each speed, which gave a group scale based on 30 values per point.

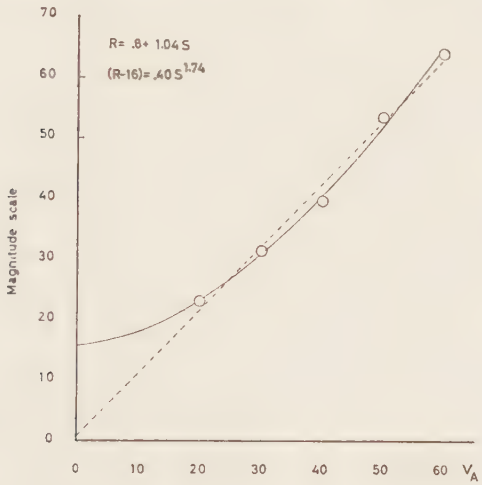

Fig. 2:3. v_A as a function of V_A, magnitude estimation (exp. 2a).

Data for experiment 2 b

Subjects: Eleven undergraduates acted as subjects. All had driving licenses.

Result of experiment 2b

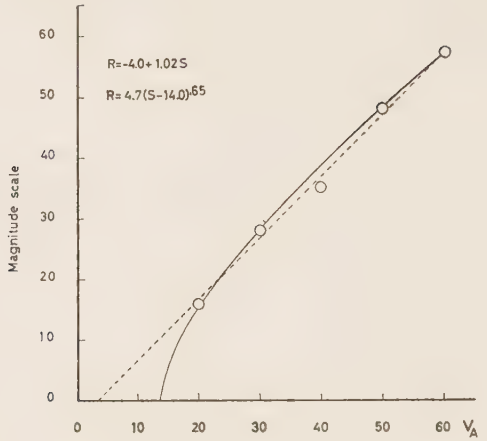

Fig. 2:4. v_A as a function of V_A, magnitude estimation (exp. 2b).

2.3.3. *Judgment of distance driven by* own *and oncoming car* (exp. 5a, b)

In motor traffic, km/h and the distance travelled in metres per unit of time are the most usual calculation units. It may be assumed that drivers are accustomed to these scales. It should therefore come natural to subjects to use these units in their judgments. Two experiments were made with this type of judgment, km/h (exp. 4) and distance driven (exp. 5). It was, however, only in the distance driven experiment that V_A had to be judged (exp. 5a).

Problem for exp. 5: How veridically can observers in a car judge the distance driven by their own and an oncoming car?

Arrangement of experiment (5a, b)

The distance (D) between the cars was always 400 m in the middle of the exposure time, i.e. 12.5 seconds after the start. Two series of starting-points were used at each end of the runway, with a displacement of 50 m. Thus there were four conditions of

starting-points. V_A and V_B were varied in steps 0, 20, 30, 40, 50 and 60 km/h, which gave a matrix with 36 combinations of speeds. In this way both cars could be used as A and B cars. Three subjects, sometimes only two, travelled in each car, and they changed places and cars in systematic order to avoid position effects. The speed combinations were randomly ordered in each matrix.

Subjects: The subjects were eleven undergraduates, all with driving licenses.

Instructions: The subjects were instructed to judge the distance driven in metres by their own and oncoming car between E's signals "Now" and "Stop". Five randomly selected combinations of speeds were used as pretests. The subjects were reminded of the instructions on several occasions in each block of 36 judgments.

Processing data and result

Geometric means were calculated for the judgment of D_A and D_B in each cell of 22 judgments in the matrix. The mean values for the rows and columns were calculated and functions adapted to the data. The scales contained 132 values per point.

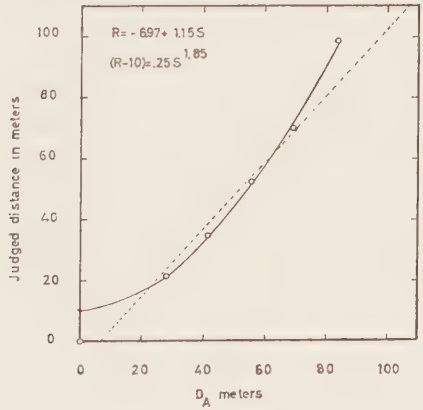

Fig. 2:5. d_A as a function of D_A, judgment of distance driven (exp. 5a).

Summary of results obtained in experiments on estimation of V_A

The scales obtained by different methods, ratio estimation, magnitude estimation and judgment of distance driven agree within the range. Veridicality is high according to all the four criteria, although exponents of the power functions deviate somewhat from unity. If the power functions and fitted lines are compared whithin the experimental range it will be found that the differences between them are small. It is also reasonable to get y-intercepts of the size the fitted straight lines give (a-values).

2.4. Experiment on the judgment of speed of (V_B) and distance driven by (D_B) oncoming car

The experiments in this field comprised ratio estimation (exp. 1 b), magnitude estimation with standard (exp. 3 a, b), judging in km/h with standard (exp. 4), and judging distance driven in metres during exposure time without standard (exp. 5 b).

The experiments with ratio, magnitude and metre estimation have been described in detail in the section dealing with the judgment of V_A. The description of the experimental set-up, instructions and the like may therefore be made brief or be ignored completely.

2.4.1. *Ratio estimation of speed of own and oncoming car* (exp. 1 b)

All the details of the problem, experimental set-up, instructions, subjects and processing of data and criteria of veridicality have been given in experiment 1 a.

Problem: How veridically can the observers in a car judge the speed of own car in percentage of the speed of another?

Result of experiment 1b (V_B)

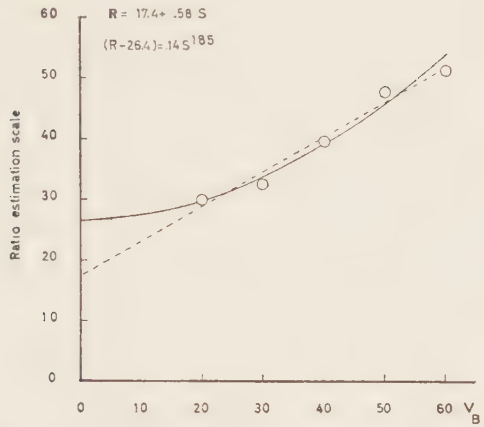

Fig. 2:6. v_B as a function of V_B, ratio estimation (exp. 1b).

2.4.2. *Magnitude estimation of speed of oncoming car* (exp. 3a, b)

These experiments were conducted in the same way as experiments 2a, b. Thus, in experiment 3a the distance (D) was 400 m at "Now" with a series of starting-points at each end of the runway. In experiment 3b the distance was 400 m at "Now" +2.5 seconds, with two series of starting-points at each end.

Problem: How veridically do observers in a car judge the speed of an oncoming car with speed of own car as standard?

Experiment 3a

Subjects: Three undergraduates and two nursing students took part. All had driving licenses.

Result

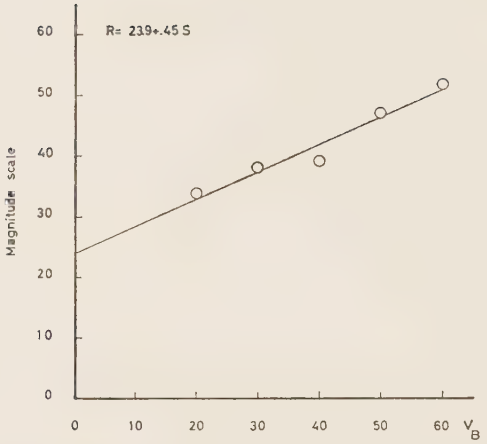

Fig. 2:7. v_B as a function of V_B, magnitude estimation (exp. 3a).

Experiment 3b

Subjects: The subjects were seven undergraduates. All held driving licenses.

Result

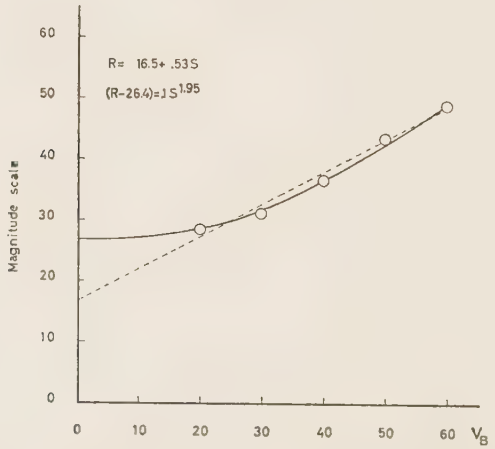

Fig. 2:8. v_B as a function of V_B, magnitude estimation (exp. 3b).

2.4.3. *Judging speed of oncoming car in km/h* (exp. 4)

A larger number of subjects (18) took part in this experiment. The aim was to obtain sufficient data for the calculation of separate scales on V_B for different V_A.

Problem: How veridically do observers in a car judge the speed of an oncoming car in km/h?

The experimental set-up was the same as for metre estimation (exp. 5), described in detail in the V_A groups (exp. 5a), point 2.3.3.

The *subjects* were eighteen undergraduates, all with driving licenses.

Instructions: The subjects were instructed to judge the speed of an oncoming car (B) in km/h. In the course of the experiment the subjects were informed every time V_A was 30 or 50 km/h (standards). Each subject accomplished two matrices, which gave a total of 72 judgments per subject.

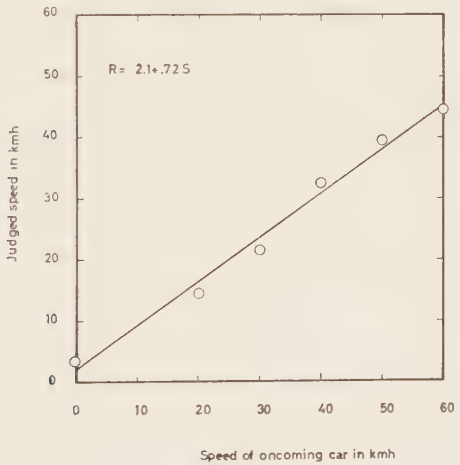

Fig. 2:9. v_B as a function of V_B, estimation in km/h (exp. 4).

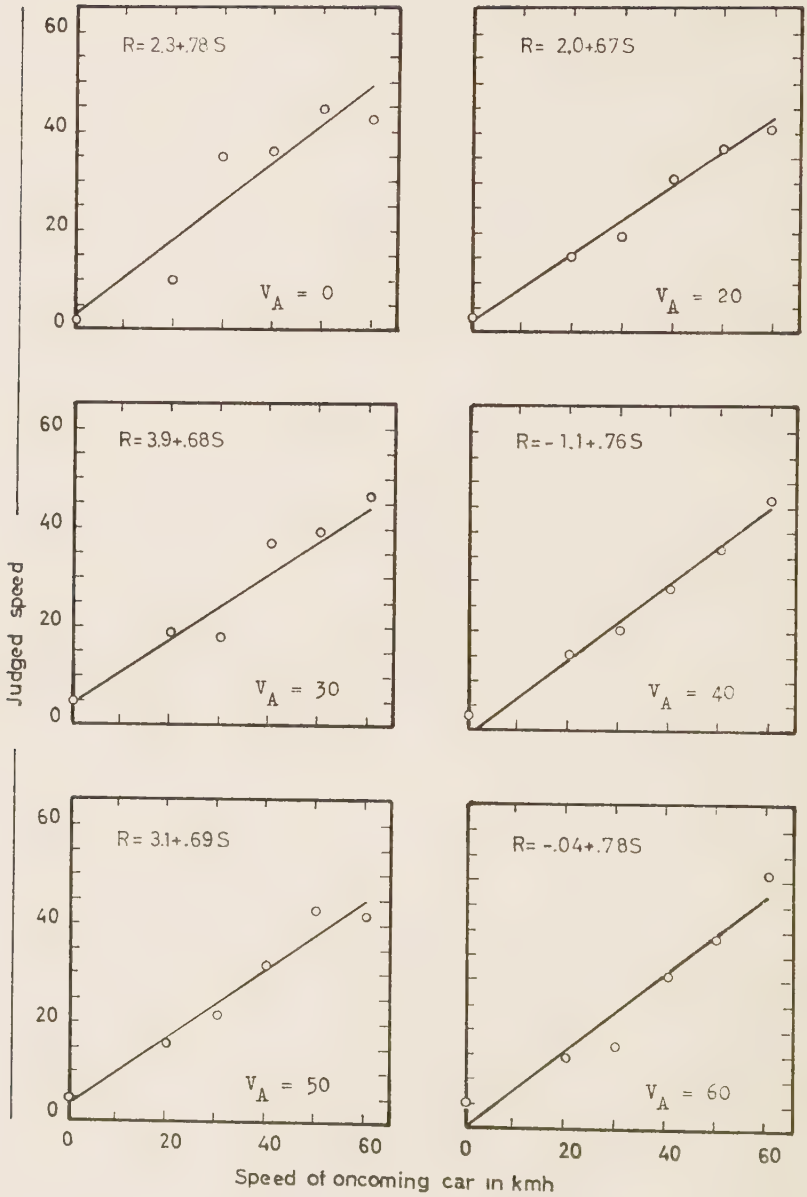

Fig. 2:10. Separate scales for V_B for different V_A (exp. 4).

Processing of data and result

Geometric means were calculated for all subjects within each cell (36 judgments). These means were then used for the calculation of the average V_B scale (216 judgments per point), separate V_B scales for each V_A (36 judgments per point).

2.4.4. *Judgment of distance driven by own and oncoming car (exp. 5b)*

For instructions, experimental set-up and subjects see exp. 5a.

Result

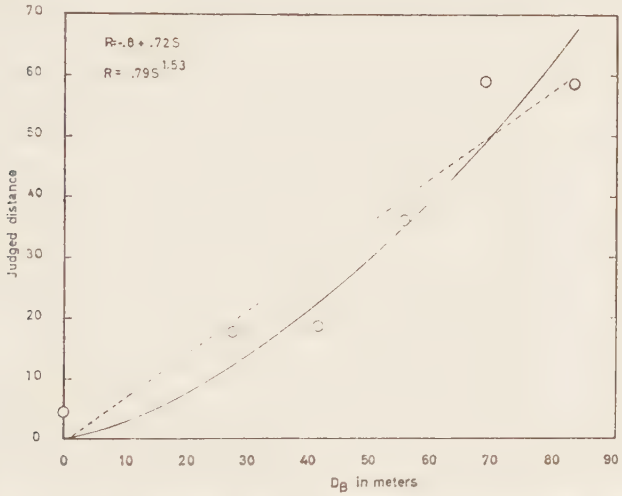

Fig. 2:11. d_B as a function of D_B, estimation of distance driven (exp. 5b).

Summary of results obtained in experiments on estimation of V_B

The scales obtained by different methods, ratio estimation, magnitude estimation, judgment of distance driven and judgment in km/h agree within the range. They deviate however from perfect veridicality according to the criteria used. The exponents of the power functions calculated deviate from unity but these deviations from linearity are very small within the

range. As can be seen from Figs. 2:7 and 2:9, the data from experiments 3a and 4 are not suitable for power functions. The important deviations from perfect veridicality are found with criteria 3 and 4 (a- and b-values).

2.5. Experiments on the judgment of speed of car in front of and driving in the same direction as own car (V_C)

Problem: How veridically can observers in a car judge the speed of a car in front of and driving in the same direction as own car?

Two experiments were made in conjunction with this problem. One (exp. 6) was performed with about the same set-up and methods as experiments 2b and 3b (magnitude estimation). The other (exp. 7) was performed with an experimental set-up and methods similar to those used in experiment 4 (estimation in km/h).

2.5.1. *Magnitude estimation of speed of car driving in front of and in the same direction as own car* (exp. 6)

Experimental set-up

The airfield used in the other experiments was too short, so the experiment was made on an airfield that was temporarily available, 1600 m long and 12 m wide. It has a concrete surface, and is somewhat more even than the shorter airfield. There is a slight depression in the middle which may have made judgments easier in two of the distances (see below).

V_A was always 40 km/h during exposure time. V_C was 20, 30, 40, 50 and 60 km/h, and varied randomly. The system of starting-points was complicated in most of the earlier experiments. In this one, however, simplifications could be introduced, for the differences in V_A–V_C give small changes in D. Two different

starting-points were used for V_C, one for 20 and 30, and one for 40, 50 and 60 km/h. This system gives a maximal difference in D between starting-points (40/20 to 40/60) of 36 m. As in the earlier experiments, D was 400 m in the middle of the exposure time. The length of the runway made possible a series of nine partial stretches with four starts in one direction and five in the other.

Subjects: The subjects were twelve undergraduates, all of whom had driving licenses.

Instructions: The subjects were instructed to assess the speed V_C in relation to V_A, which was called "50". They were not allowed to observe C except during the exposure time. Each subject made 50 estimations.

Processing of data and result

Geometric means were calculated for all speeds, which gave a group scale based on 120 values per point.

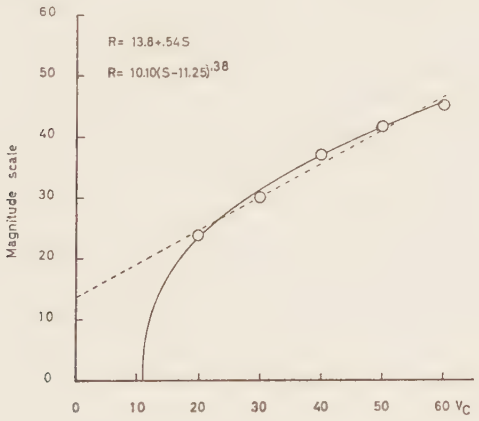

Fig. 2:12. v_C as a function of V_C, magnitude estimation (exp. 6).

2.5.2. *Judging speed of car driving in front of and in same direction as own car in km/h (exp. 7)*

Arrangement of experiment

This experiment was made on the same airfield as experiment 6. Two standard speeds were used for V_A, namely 30 and 50 km/h. V_C was varied within the range 0, 20, 30, 40, 50 and 60 km/h. The same system was used for V_C as in experiment 6.

Subjects: Eleven undergraduates acted as subjects. They all had driving licenses.

Instructions: The subjects were instructed to judge the speed of C in km/h. They were told the speed of A, which was either 30 or 50 km/h.

Processing of data and result

Forty-four values were obtained for each combination of speeds. Medians were then calculated on these. This calculation of the median was used partly because 0-values were present and partly because the distributions were skewed. The median values were then used to calculate the average V_C scale and separate scales for the standards 30 and 50 km/h.

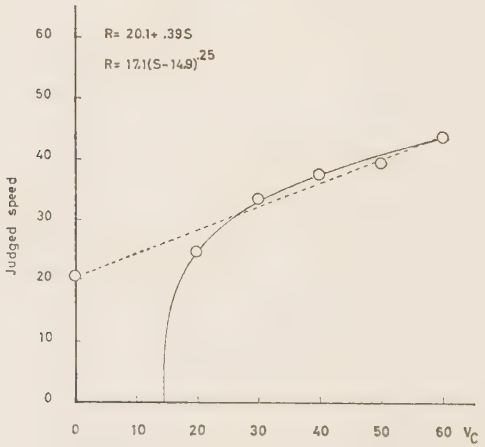

Fig. 2:13. v_C as a function of V_C, estimation in km/h (exp. 7).

Summary of results obtained in experiments on estimation of V_C

The scales obtained by the two methods, magnitude estimation and judgment in km/h agree within the range. The deviations from perfect veridicality are very similar to those found in the experiments on V_B.

2.6. Summary of results of experiments 1–7 referring to judgments of V_A, V_B and V_C

Problem 1. How veridically do drivers judge V_A, V_B and V_C? Generally speaking, judgments of V_A show a number of usually rather small deviations from perfect veridicality, while judgments of V_B and V_C show great deviations. Ability to discriminate V_B and V_C is markedly poor.

Problem 2. In what way do drivers' judgments of V_A, V_B and V_C differ with reference to veridicality?

The answer to this question is given in the tabulated summary of the results of experiments 1–7.

Criterion 1 (linearity) does not discriminate speed groups. The exponents of power functions show positive acceleration for V_A and V_B and negative acceleration for V_C. The deviations from linearity within the experimental range, however, are all small.

The second criterion does not separate the speed groups.

The third criterion separates the V_A-group from the others.

The fourth criterion also separates the V_A-group from the others.

Summary of results of experiments 1–7.

Exp. no.	Type of judgment	Data for straight lines		Data for power functions			Criterion of perfect veridicality
		a	b	n	y-intercept	S_0	
	V_A						
1 a	Ratio estimation	−2.2	1.04	2.14	17.6	—	1, 3
2 a	Magnitude estimation	0.8	1.04	1.74	16.0	—	1, 3, 4
2 b	Magnitude estimation	4.0	1.02	0.65	—	14.0	1, 2, 4
5 a	Distance driven in m without standard	−7.0	1.15	1.85	10.0	—	1, 3
	V_B						
1 b	Ratio estimation	17.4	0.58	1.85	26.4	—	1, 3
3 a	Magnitude estimation	23.9	0.46	—	—	—	1, 2, 4
3 b	Magnitude estimation	16.5	0.53	1.95	26.4	—	1, 2, 4
4	km/h with standard	2.1	0.72	—	—	—	1, 2, 4
5 b	Distance driven in m without standard	0.8	0.72	1.53	0.0	—	1, 3
	V_C						
6	Magnitude estimation	13.8	0.54	0.38	—	11.3	1, 2, 4
7	km/h with standard	20.1	0.39	0.25	—	14.9	1, 2, 4

CHAPTER 3

COMBINATION OF DATA FROM PREDICTIVE JUDGMENTS OF MEETING POINT WITH DATA FROM JUDGMENTS OF SPEEDS AND DISTANCES

The purpose of Chapter 3 is to combine data from predictive judgments of meeting point (Björkman, 1963) with my own data for the individual subjective variables (v_A, v_B and d) included in the predictive judgments. Björkman's experiment gives information on behaviour at the prediction of meeting place in terms of systematic error—the difference between objective and subjective meeting place—on the S continuum. This systematic error may be assumed to be due to lack of veridicality in judging the individual situation variables, and to lack of ability to organize and combine the items of information.

3.1. Brief description of Björkman's experiments and results

Three experiments were made. One of them (exp. 2) referred to training effects in the prediction of meeting place. The other two were concerned with the prediction of meeting place between cars A and B (exp. 1) and the simultaneous judgments of the mid-point between A and B. The airfield used by Björkman was the same as that used in my experiments. The distance (D) varied between 450 and 300 m, and the meeting stretch was divided into sections by seven white tiles at intervals of 50 m. The subjects were to give the meeting place and mid-point respectively, with the help of this system of tiles. The speeds of the cars were 20, 30, 40, 50 or 60 km/h, giving a total of twenty-five combinations.

Results

Exp. 1. Plotting the prediction error y (the difference between subjective and objective meeting point) against the distance between objective mid-point and objective meeting place gives $y = 0.89x + 0.3$. This shows that the subjects, generally speaking, located the meeting place to the mid-point.

Exp. 2. The subjects were trained by allowing them to observe the objective meeting place, which gave a reduction of the b-value (cf. equation in exp. 1) by about 30 per cent.

Exp. 3. Plotting the difference between the subjective and objective mid-point, z, against x gives $z = 0.13x - 2.0$. The subjective mid-point has thus a slight tendency to covary with the distance between mid-point and meeting place.

3.2. Principles of the combination of data

The model to be used in the combination of data is based on the assumption that the observer judges the meeting place to be at a point that divides the subjective distance (d) in the same relation as the relation between the subjective speeds. (Fig. 3:1).

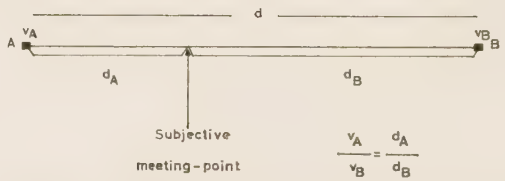

Fig. 3:1. Illustration of the assumption of the relation between subjective speeds (v_A, v_B) and the subjective distances (d_A, d_B) of the cars to the subjective meeting place.

Given the subjective equivalents of V_A, V_B and D, the location of the meeting place can be calculated according to this hypothesis of the behaviour at the prediction of meeting point. Differences at the prediction of meeting place thus calculated

and those obtained in Björkman's experiments can then be interpreted as an expression of the difficulty the subject has in using his scales to predict the meeting place.

For each of the twenty-five combinations of speeds in Björkman's experiment we can, with the help of data from Chapter 2, determine the ratio between the subjective speeds. Let these ratios be called q_{AB}. In order to get these ratios we use experiments 1 (ratio estimation) and 5 (metre estimation), in which the ratio can be calculated between subjective distances driven by A and B.

The gap (D) between the cars in experiments 1 and 5 at the moment when judgments were made was not exactly the same as in Björkman's experiment. To make it possible to use the subjective ratios to divide the distance between the cars, a measure of the subjective distance must be determined. Data from Björkman's third experiment have been used to get some idea of the subjective distance. $S_{\frac{1}{2}}$ has been plotted against S, which gave the fitted line the gradient 0.56 (Fig. 3:2).

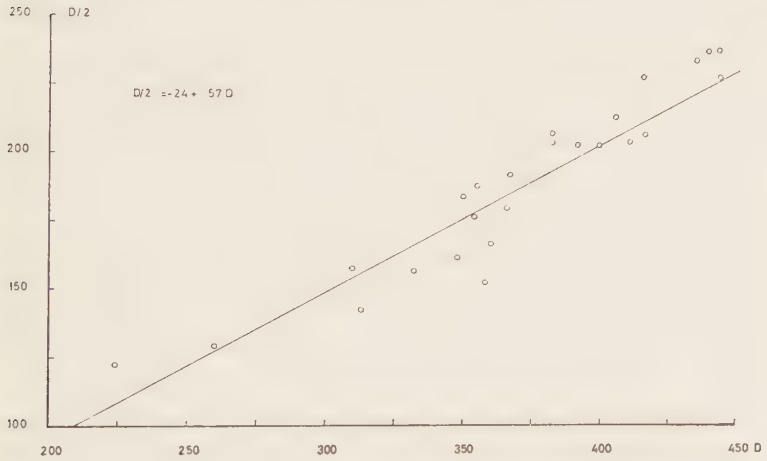

Fig. 3:2. Plotting $S_{\frac{1}{2}}$ against S for distance (Björkman's data).

The results show, according to Fig. 3:2, that the relation between subjective and objective distance is rather close to linear in this case. The R–S function calculated from the data in this case has the exponent 1.23. The result is in good conformity with the results of experiments on static judgments of shorter distances, where almost perfect agreement is obtained between subjective and objective distance (Gibson, Bergman & Purdy, 1955; Purdy & Gibson, 1955).

In order to illustrate further the relation between subjective and objective distance, I made a complementary experiment. The problem was to investigate static judgment of distances to and between motor-cars on an ordinary asphalt highway.

3.3. Judgment of distances to and between cars on an ordinary asphalt highway

The subjects stood in the middle of the left lane of a straight, two-lane highway. Two motor-cars (B, C) were standing in such way that car B was in the right lane turned towards the subjects, and car C was in the left lane turned away from the subjects. Car B was always farther away than car C. The distance from the subjects to car B (total distance) was given the value 600, 500, 400 or 300 m. The distance between the cars was 200, 150, 100 or 50 m. The combinations of distances for judgment were given randomly and the exposure time was five seconds. The sixteen combinations were judged twice. Two different instructions were given: (a) The subjects were told to judge the total distance and distance between cars in metres simultaneously. (b) The subjects were told to judge the distance between the cars in percentage of the total distance. Thirty-two subjects made two judgments of each combination (16) according to instructions (a), which gives a total of 1024 judgments, while twenty-one subjects

made two judgments of each combination (16) according to instructions (b), 672 judgments in all.

The judgments made according to instructions (a) were transformed into ratios, after which the subjective ratios were plotted against the objective ratios. Agreement was good. Adaptation to a rectilinear line according to the method of least squares gave mean b-values of 1.03 for both instructions, while the a-values could be neglected in both cases. Subjective ratios according to instructions (a) were plotted against subjective ratios according to instructions (b). An adapted rectilinear line gave a mean b-value of 1.0, and the a-value was negligible.

Starting from the data on judgments of distance given above, it is reasonable to assume that the exponent for a R–S function for distance is around 1. This implies that the calculations at the combination of the subjective variables v_A, v_B and d can be made on the basis of $d = D$. If meeting places calculated from the subjective variables, v_A, v_B and d, were in complete agreement with Björkman's data, the whole difference between objective and subjective meeting point would, with $d = D$, depend on the difference between subjective and objective speeds.

3.4. Calculations and figures

The calculations necessary for the combination of data are as follows (the ratio matrices will be found in the Appendix):

1. The subjective ratios, q_{AB}, for all the combinations are calculated for data from experiments 1 (ratio estimation) and 5 (estimation of distance driven) in Chapter 2.
2. The objective ratios Q_{AB} are calculated from the S matrix.
3. The ratios D_A/D_B are calculated from Björkman's data.

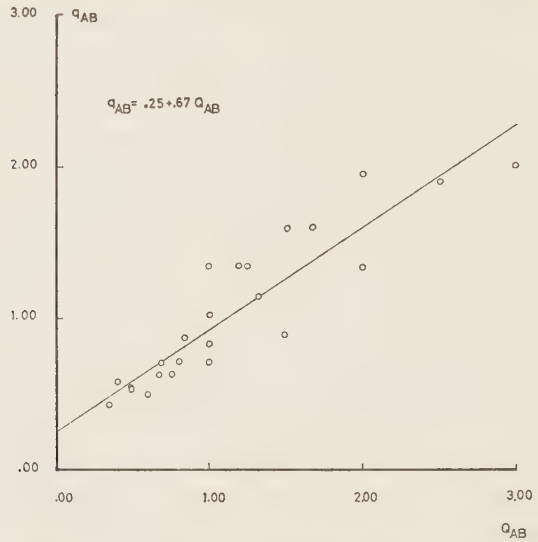

Fig. 3:3. Ratios (q_{AB}) from ratio estimation (exp. 1) plotted against objective ratios (Q_{AB}).

3.5. Result and discussion

The inference of the tendency in the plottings is simple. The judgments made by the subjects expressed in ratios (q_{AB}) are rather veridical (Figs. 3:3 and 3:4). On the other hand, the predictive judgments of meeting places are practically wholly uninfluenced by the speed ratios experienced. This implies that the greater part of the prediction error is due to inability to apply and combine information on differences in speed. In so far as the assumption of perfect conformity between subjective and objective distance is erroneous, the final result will not be changed essentially if the exponent deviates from 1 within reasonable limits. According to calculations made with transformed subjective ratios, no decisive effects arise on the final result if the exponent 1.23 is used.

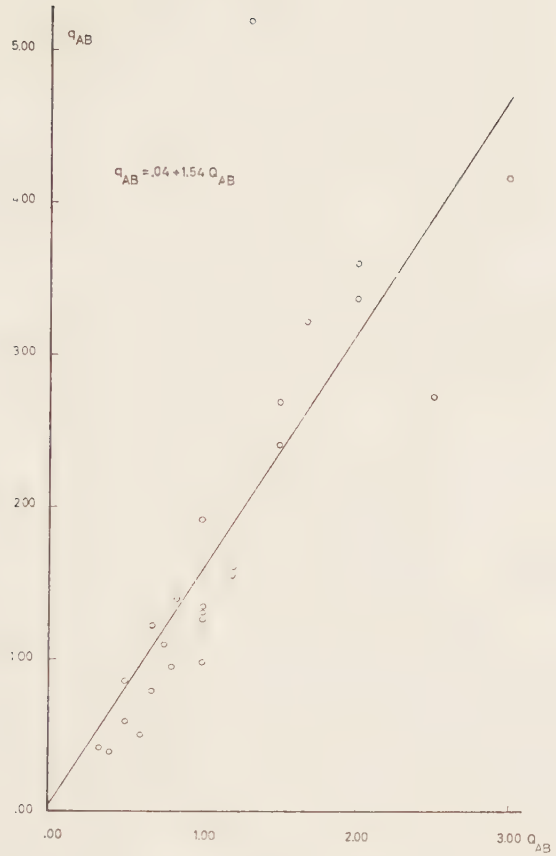

Fig. 3:4. Ratios (q_{AB}) from judgments of distance driven (exp. 5) plotted against objective ratios (Q_{AB}).

The judgments expressed in ratios for experiment 1 give a somewhat better veridicality than a combination of the individual scales (see Chapter 2) according to degree of veridicality of the rectilinear line. This is probably connected with the obvious curving of the regression line in the lower speeds, whereby errors neutralize each other to a certain extent.

The great increase in errors appearing when simultaneous information is to be combined for predictions is interesting from

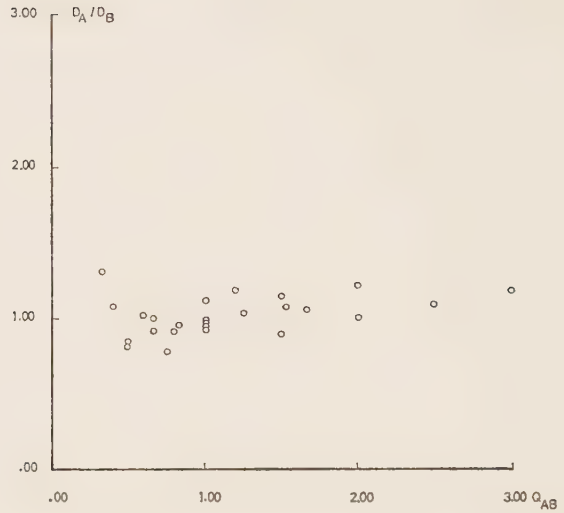

Fig. 3:5. Ratios (D_A/D_B) from Björkman's exp. 1 plotted against objective ratios (Q_{AB}).

practical aspects, too. The behaviour of drivers comprises to a great extent predictive judgments with, quite often, many variables. Overtaking, for example, requires judgments of speeds of own and other cars, distances between them, the acceleration needed for overtaking, and so on.

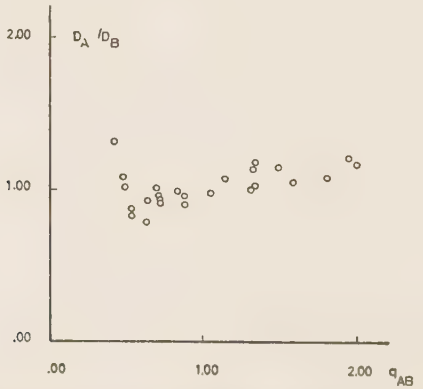

Fig. 3:6. Ratios (D_A/D_B) from Björkman's exp. 1 plotted against ratios from exp. 1 (q_{AB}).

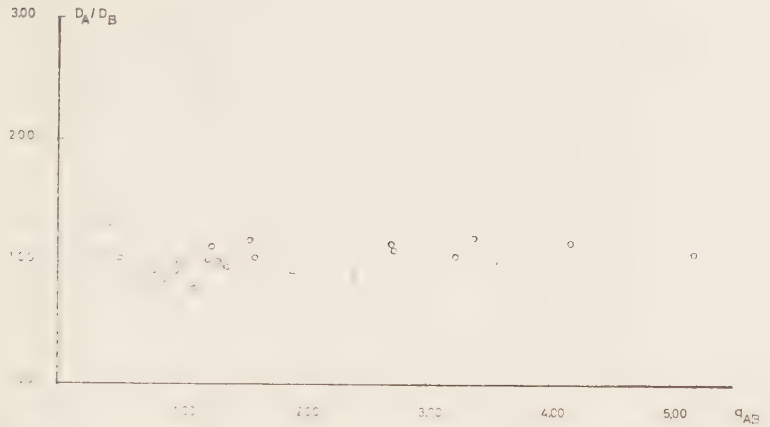

Fig. 3:7. Ratios (D_A, D_B) from Björkman's exp. 1 plotted against ratios from exp. 5 (q_{AB}).

Results arrived at by Gottsdanker & Edwards (1957) in laboratory experiments form an interesting parallel. They used a prediction situation in which two targets moved down perpendicular paths towards an intersection, but disappeared before reaching it. The subjects estimated where one target would be when the other crossed the intersection. The results indicate that for accelerated and constant-speed targets the prediction was based on relative positions at the time when the targets disappeared rather than on relative speeds or accelerations.

Björkman, in his second experiment (Björkman, 1963), studied the effect of training on the prediction of meeting place. The error was reduced by about 30 per cent during the training period. It is impossible, on the basis of the data available, to say exactly how the improvement arises. Assessments of distances and speeds can be improved, as can ability to combine data for prediction purposes. It is also feasible that subjects learn to make use of certain features of the experimental situation. Most likely, they did not learn to discriminate the sensory input better,

but rather learned to combine it and connect it with the response categories. Further investigations are being made on the prediction of meeting place. Brehmer (1963) is studying, among other things, learning effects in this connection, and is using a smaller number of speed combinations and response categories. Hitherto, the results point in the same direction as Björkman's. The distances (D) used by Brehmer are the same as in experiment 5 (Chapter 2), i.e. 400 m in the middle of the exposure time.

CHAPTER 4

JUDGMENTS OF SPEED OF ONCOMING CAR AND OF CAR DRIVEN IN FRONT OF AND IN SAME DIRECTION AS OWN CAR (V_B, V_C) WITH VARIATIONS OF LATERAL DISTANCE

4.1. Introduction

The experiments on the judgments of V_B and V_C described in Chapter 2 show that the judgments are lacking in veridicality in the prevailing experimental conditions. In the V_B experiments the cars were driven straight towards each other, each along a separate lane with a lateral distance of about 5 m between them, measured from the subject to the centre of B. The gap (D) between the cars, in the direction of travel, was, except for a few experiments, 400 m in the middle of the exposure time, and V_B was varied within the speed range 0 to 60 km/h. Thus the experimental situation did not include variations in D or in lateral distance, if experiments 6 and 7, concerning the assessment of V_C, in which the cars drove in the same direction along the same lane, are ignored. A lateral distance of 5 m was chosen as being most representative of a normal meeting situation on a large highway.

These physical conditions, which are kept constant in experimental situations, are changing continually in actual traffic situations. Thus the lateral and total distances at judgments vary, and the road is more or less bent horizontally and vertically.

Obviously, information on and thereby the experience of the motion of motor-cars alters when the traffic situation is changed

in this way. The investigation program for the exploratory analysis of judgments of speed also includes such factors. Among the physical variables, which should be important in this connection, the lateral distance was chosen as an independent variable in the following experiments. It proved necessary, however, to determine more exactly the movements of the cars and how these movements could be best described from the angle of stimulus.

4.2. Stimulus analysis of experimental situation

In laboratory experiments on the perception of motion, a stimulus situation in which the object moves on a screen vertical to the eye is generally employed (Brown, 1961). This two-dimensional situation is relatively simple from the aspect of stimulus. This stimulus is usually expressed in terms of size and changes in angle of vision. Angle of vision, i.e. the angle the moving stimulus occupies in the eye, can be used in the determination of absolute thresholds and discriminating thresholds with a measure independent of variations in observation distance (Graham, 1951).

In the present experimental situation, e.g. exp. 3b, the description of the stimulus becomes more complicated. The distal stimulus situation (Gibson, 1950) is characterized by the oncoming car moving along (exps. 6, 7) or parallel to the axis of vision of the observer in the A car. Thus there is also a three-dimensional case. For an analysis of this we can turn to stimulus analyses made in air traffic (Gibson, Olum & Rosenblatt, 1955; Hochberg & Smith, 1955).

The starting point is a distinction between distal and proximal stimuli. By distal stimulus is meant the object reflecting light energy to the eye. It is not altered, naturally, by changes in the position and movement of the subject. Proximal stimulus

refers to the pattern of the light energy from distal stimuli usually described as the distribution of light on the retina. Proximal stimulus forms the stimulus for the subject. In the following the term stimulus always means proximal stimulus.

The authors mentioned above have not used the direct retina picture but its projection on a picture plane (P) in their descriptions of stimuli. This picture plane is assumed to be located between the subject and distal stimuli, and at right angles to the direction of the subject's movement. The eye forms the station point (o) in the projection system, but since it moves parallelly with the road and straight forward, the line of motion of the eye and the extension of the line of motion to the point of infinity (F), may also be used in descriptions (Fig. 4:1).

Fig. 4:1. Sections of road projected on a picture plane.

The changes in angles at the eye caused by alterations on the picture plane are of several kinds. The movement towards infinity causes an expansion flow out from the point of infinity, where the angle velocities are low near infinity and more rapid farther out (Fig. 2, Gibson, Olum & Rosenblatt, 1955). The projection of an object that is immediately in front of the point of infinity expands in this way. If this object (car B) approaches with its own speed, there will also be expansion in the projected surface due to the velocity of B.

When, on the other hand, B is at the side of the point of infinity (F), there will be a lateral displacement of B's projection on the picture plane (P) as B approaches. Fig. 4:2 shows how

this displacement arises. Thus the "picture" of the car expands on the picture plane owing to the fact that the distance between the cars decreases at the same time as it is displaced to the right. (For the meaning of the symbols f, h, l, t_1 and t_2 see the account below of the calculation of changes in the angle of vision.)

The calculations of the changes in angle of vision have been made as follows. Assume for the time being that car A and therefore the station point of the system (the eye) are stationary (cf. Fig. 4:2).

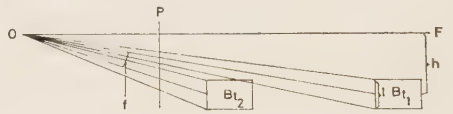

Fig. 4:2. Expansion and lateral displacement on the picture plane (seen from above) of the projection of car B between two subsequent points of time when $V_A = 0$.

1. When the cars are driving straight towards each other, the width of the cars (l) is divided by D for two subsequent points of time, t_1 and t_2, during the exposure time, whereby the change in the angle of vision (e) will be $e = l/D_{t_1} - l/D_{t_2}$.

2. When the cars are driving straight towards each other but at a certain lateral distance (h) changes in angle of vision will arise in relation to the line eye to point of infinity;

$$f = \frac{h}{D_{t_1}} - \frac{h}{D_{t_2}}.$$

Then the lateral displacement arising in the projected picture has not been added.

Angle velocity is dependent on the size of V_B. It also changes dependent on the size of V_A. From the aspect of perception, however, distinction must be drawn between the expansion arising on account of one's own motion, and that arising from the

movements of cars B and C. This perceptual subtraction of the two movements has been demonstrated by Johansson (1950, 1958, 1963). Data from the experiments described in Chapter 2 also provide direct confirmation of the phenomenon. Fig. 2:9 shows that the judgement of V_B is not affected by V_A.

4.3. Description of situations chosen

The main purpose of the choice of situations was to find some typical meeting situations in traffic, and to study them experimentally from the aspect of assessing speed. The following situations were chosen:

Situation 1: The cars drove straight towards each other along the same lane. The angle displacement then arising is due to the fact that the "picture" of car B expands round the point of infinity. Experiments 6 and 7, Chapter 2, on V_C refer directly to Situation 1, but in them the change of angle is in the opposite direction. Magnitude estimation was used in experiment 6, and the data obtained has therefore been employed. A special experiment was made with the judgment of V_B (exp. 8a).

Situation 2: The cars drove along separate lanes with a lateral distance of 5 m between the subject and the centre of the other car. Two types of angle displacement arise; one of the same kind as in Situation 1, the other caused by the lateral motion of the "picture". The experiments in Chapter 2 referring to V_B belong to this type, so the data from those experiments were used. To get some relation to night driving, an experiment was performed on the judgment of V_B in the dark, when both A and B were driving with dipped headlights (exp. 9).

Situation 3: The cars drove along separate lanes with a lateral distance of 25 m between the subject and the centre of the other car. The same two kinds of angle displacement arise here as in Situation 2. This experiment (8b) was made to obtain an angle

displacement more representative of situations on hills and at bends where greater angle velocity occurs than in Situation 2. A new experiment was made here (exp. 8b).

Situation 4: The cars drove along lanes that crossed each other at an angle of 90°. This gave a very high angle velocity and a situation similar to a crossroad. The situation was also like the two-dimensional case in laboratory experiments. A new experiment was made here (exp. 8c).

4.4. Calculations of angle velocities for the different experimental situations

The set-up for the following experiments was the same in all cases. Magnitude estimation with $V_A = 40$ km/h as standard was used consistently. V_B and V_C were given the values 20, 30, 40, 50 and 60 km/h, and D was always 400 m in the middle of the exposure time.

The calculations were made on angle velocity during the last second of the exposure time. The "base" of the triangle in the calculation of the angles was, for Situations 1, 2 and 3, 1.6 m, 5 m and 25 m respectively.

Angle velocity ("/sec) for different V_B and V_C respectively in experimental situations 1–3

V_B and V_C resp. in km/h	20	30	40	50	60
Situation 1 exps. 6, 8 a	11	19	26	33	41
Situation 2 exps. 3 b, 9	38	59	80	104	128
Situation 3 exp. 8 b	190	291	400	519	637

In Situations 2–3 the angle velocity refers to the lateral movement of the "picture". The angle velocity that arises by expansion of the "picture" was not included in the calculations.

The angle velocity in exp. 8c was not calculated since this value could not be used for calculations of z-values. The p-values were 0 or 100 per cent for three of the five speeds.

4.5. Method of processing the data

The following computations were made for each experiment in each situation (with certain exceptions for exp. 8c).

a. The data were processed in the same way as in magnitude estimation experiments in Chapter 2. Geometric means were calculated for all judgments at each speed, and a subjective group scale obtained. Comparableness with results in Chapter 2 was achieved, and the veridicality criterion of magnitude estimation (1, 2 and 4) could be used.

b. In order to determine in greater detail the discrimination of the differences in speed between the standard ($V_A = 40$ km/h) and different V_B and V_C respectively, data from each experiment were processed as with the method of constant stimuli. Since the standard was in the middle of the V_B and V_C distributions, percentiles were calculated according to "less than", "same as" and "greater than". The "same as" judgments were distributed proportionally among "smaller than" and "greater than". After that the z-values were calculated for "greater than" and a rectilinear line was adapted to data according to the method of least squares. The z-values were then plotted against the km/h and ″/sec of the stimulus continuum, after which a rectilinear line according to the method of least squares was adapted to data. In this figure ΔS can be determined graphically as half the distance of $+1$ z to -1 z and S as a point of intersection between the adapted rectilinear line and the x-axis ($z = 0$) respectively.

c. The processing of data according to point 2 was complemented by calculation of the discriminal dispersion (σ_R). Since

each subject made rather many judgments per speed (V_B and V_C respectively), the standard deviation was calculated for each subject's judgments of each speed, and after that an average standard deviation ($\bar{\sigma}_R$) was calculated. The $\bar{\sigma}_R$ obtained was then plotted against $\bar{R}$ (group value). In this way, information could also be obtained from data if Weber's law is valid for stimulus variables (point 2) and corresponding subjective variables (point 3). Thus possibilities are obtained of linking up with the question of whether speed is a prothetic or metathetic continuum (Stevens, 1957).

4.6. Experimental section

The report of the experiments follows the division into situations given under point 4.3. The results of the experiments are reported, with certain exceptions for experiment 8c, in the form of three figures: (a) subjective speed as a function of physical speed (b) plotting of z-values for "greater than" against ″/sec and V_B and V_C respectively, (c) plotting of $\bar{\sigma}_R$ against $\bar{R}$. Tables of detailed data will be found in the Appendix.

The arrangement of the experiments in Chapter 4 was the same for all the experiments, apart from the variation in lateral distance and night driving. Magnitude estimation with a standard ($V_A = 40$ km/h) was used, and V_B and V_C respectively took the values 20, 30, 40, 50 and 60 km/h. The distance (D) was 400 m in the middle of the exposure time, i.e. at "Now" +2.5 seconds, with the exception of experiment 8c, in which the distance between the cars on the lanes was 500 m. The set-up was, apart from D in experiment 8c, the same as in several magnitude estimation experiments in Chapter 2, e.g. experiment 3b.

General problem: How does veridicality differ in judgments of speeds of other cars (V_B, V_C) in some selected traffic situations (Situations 1–4)?

4.6.1 *Situation 1*

In this situation both cars drove along the same lane. Data from exp. 6, magnitude estimations of V_C were used. In addition, a new experiment was made (exp. 8a) with magnitude estimation of V_B.

Experiment 8a: Magnitude estimation of the speed of oncoming car (V_B) with speed of own car as standard. The cars drove along the same lane.

Subjects: Thirteen undergraduates, all holders of driving licenses, participated.

Result: The group scale (geometric mean), is based on 130 judgments per point.

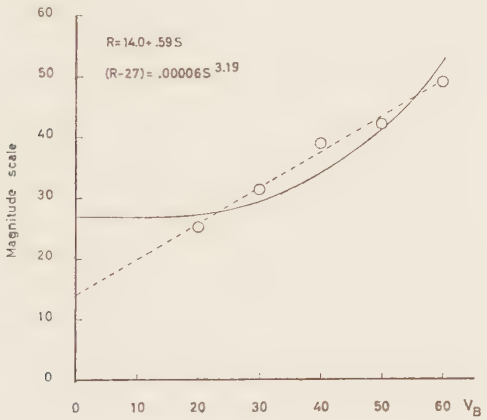

Fig. 4:3. v_B as a function of V_B, magnitude estimation (exp. 8a).

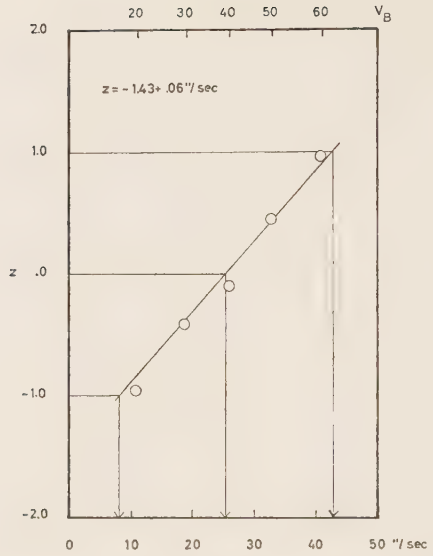

Fig. 4:4. z-values for "greater than" plotted against "/sec and V_B (exp. 8a).

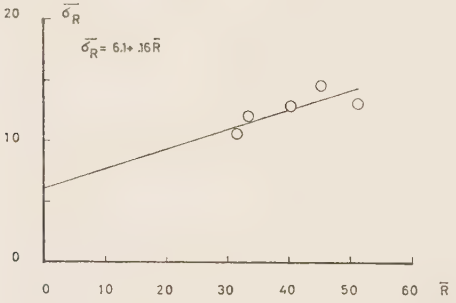

Fig. 4:5. $\overline{\sigma}_R$ plotted against $\overline{R}$ (exp. 8a).

Experiment 6: Magnitude estimation of speed (V_C), of a car driving in front of and in the same direction as own car with speed of own car as standard. The cars drove along the same lane (cf. account of the experiment in Chapter 2).

Result: The group scale (geometric mean) is based on 120 judgments per point.

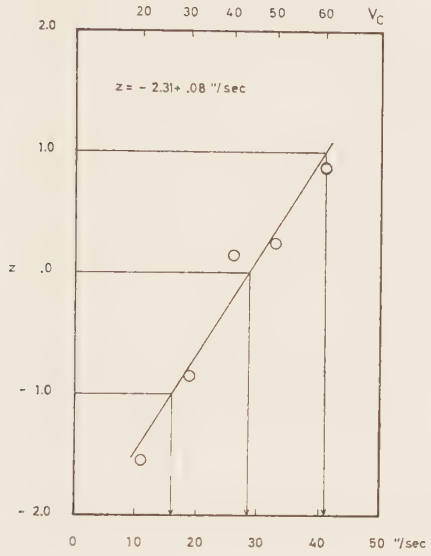

Fig. 4:6. z-values plotted against "/sec and V_C (exp. 6).

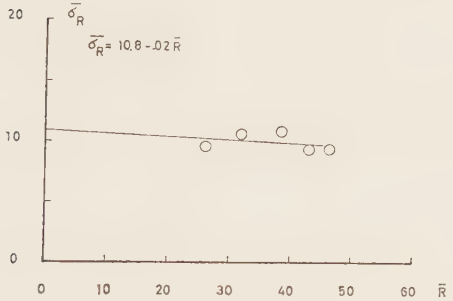

Fig. 4:7. $\bar{\sigma}_R$ plotted against $\bar{R}$ (exp. 6).

For v_C as a function of V_C, see Fig. 2:12.

4.6.2 *Situation 2*

In this situation the two cars drove along separate lanes with a lateral distance of ca. 5 m between them, measured from the subjects in car A to the centre of car B. Data from experiment 3b, magnitude estimation of V_B were used. As a special addition, an experiment with magnitude estimation of V_B was made in night driving.

Experiment 3b: Magnitude estimation of speed of oncoming car (V_B) with speed of own car as standard. The cars drove in separate lanes at a lateral distance of 5 m (cf. account of the experiment in Chapter 2).

Result: The group scale (geometric mean) is based on 70 judgments per point.

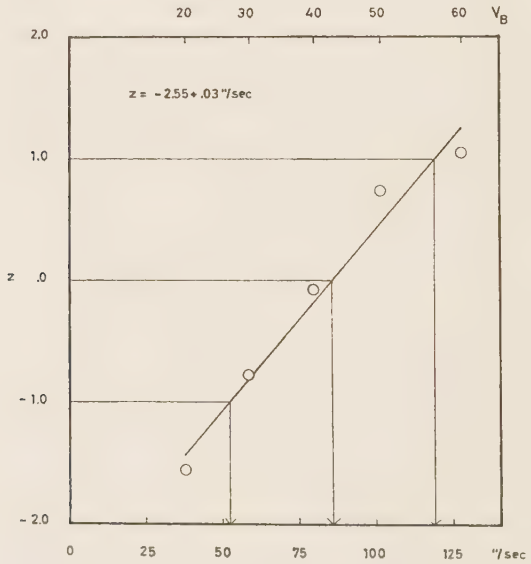

Fig. 4:8. z-values plotted against "/sec and V_B (exp. 3b).

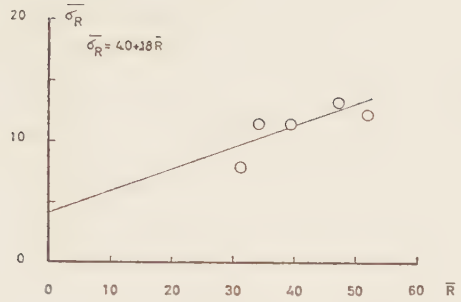

Fig. 4:9. $\overline{\sigma}_R$ plotted against $\overline{R}$ (exp. 3b).

For v_B as a function of V_B, magnitude estimation, see Fig. 2:8.

Experiment 9: Magnitude estimation of speed of oncoming car (V_B) with speed of own car as standard. The cars drove along separate lanes at a lateral distance of 5 m from each other. The experiment was made in the dark with dipped lights on both cars.

The other experiments (1–8) were made in daylight, mostly in cloudy weather. Some days were bright, at times with strong sun. Rainy weather was avoided, for at times it was difficult to maintain satisfactory visibility through the front windscreen in rain. It seems obvious, however, that the possibility of estimating speed and judging meeting-place will be impaired when visibility and contrast are modified by darkness, rain, mist, snowstorms and the like. The problem is great and complicated, and only a small, limited situation has been chosen for an exploratory experiment, *night driving with dipped headlights.*

The experiments (judgments) were made on 16, 17 and 20 May 1963, between 10.00 p.m. and 12.00 p.m. The cars were equipped with normal lights with two headlights and parking lights with a total of 90 W per car. The subjects sat for about a quarter of an hour to adapt themselves to the dark, at the same time as they received their instructions.

Subjects: Ten undergraduates took part. All of them had driving licenses.

Result: The group scale (geometric mean) is based on 100 judgments per point.

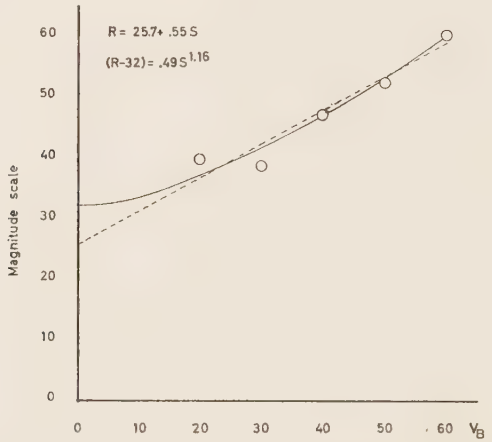

Fig. 4:10. v_B as a function of V_B, magnitude estimation (exp. 9).

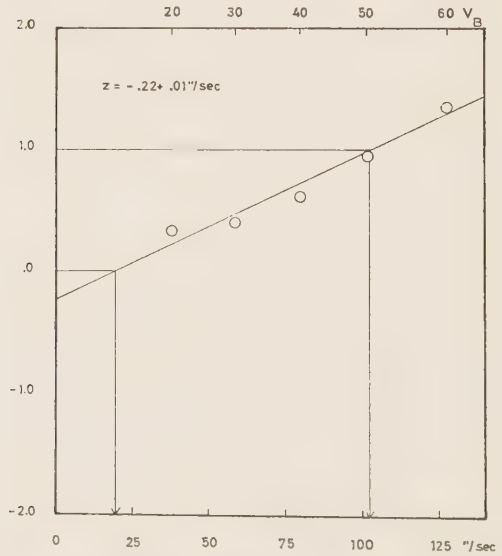

Fig. 4:11. z-values plotted against "/sec and V_B, magnitude estimation (exp. 9).

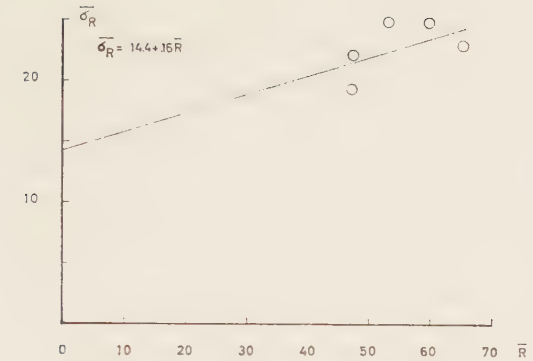

Fig. 4:12. $\bar{\sigma}_R$ plotted against $\bar{R}$ (exp. 9).

4.6.3. *Situation 3*

In this situation the two cars drove along separate lanes at a lateral distance of about 25 m from each other, measured from the subjects in car A to the centre of car B.

Experiment 8b: Magnitude estimation of speed of oncoming car (V_B) with speed of own car as standard.

Subjects: Eight undergraduates, all holders of driving licenses, participated.

Result: The group scale (geometric mean) is based on 80 judgments per point.

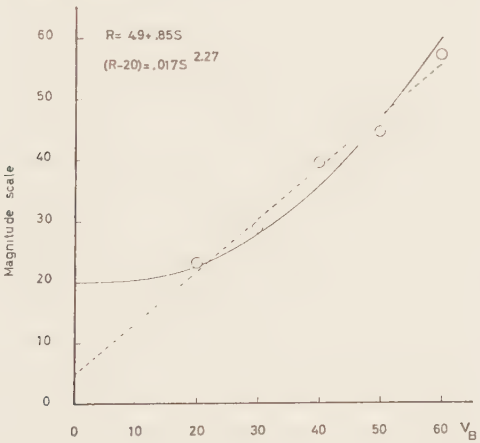

Fig. 4:13. v_B as a function of V_B, magnitude estimation (exp. 8b).

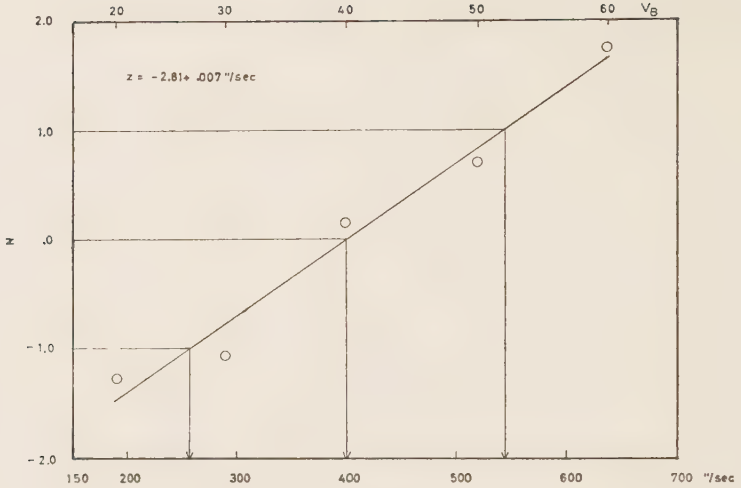

Fig. 4:14. z-values plotted against "/sec and V_B (exp. 8b).

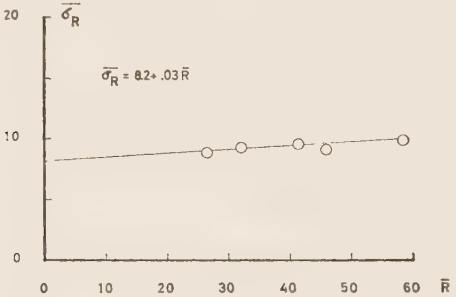

Fig. 4:15. $\bar{\sigma}_R$ plotted against $\bar{R}$ (exp. 8b).

4.6.4. *Situation 4*

In this situation cars A and B drove towards each other along separate runways of the airfield, so that the lanes formed an angle of 90°. The total distance from the cars to the crossing was 500 m in the middle of the exposure time. The total distance was thus increased by 100 m to allow for the shortened direct distance between the cars. The distance to the crossing was divided so that is was 225 or 275 m. The cars changed sides and positions in random order. Four position conditions were obtained in this way.

Experiment 8c. Magnitude estimation of speed of oncoming car (V_B) with speed of own car as standard.

Subjects: The subjects were twelve undergraduates, all with driving licenses.

Result: The group scale (geometric mean) is based on 120 judgments per point.

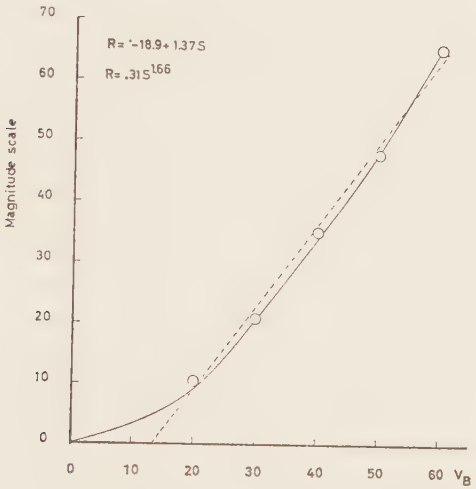

Fig. 4:16. v_B as a function of V_B, magnitude estimation (exp. 8 c).

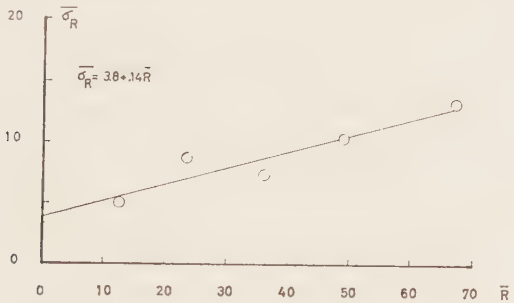

Fig. 4:17. $\overline{\sigma}_R$ plotted against $\overline{R}$ (exp. 8 c).

The z-values were not plotted, for the p-values were 100 per cent and 0 per cent for three of the five speeds (see Appendix).

4.7. Analysis of data and discussion

4.7.1. *Summary of results*

In order to facilitate analyses of data and discussion, a summary of results of experiments in situations 1–4 is given in table form.

Summary of results from experiments within situations 1–4

Sit. no and exp. no.	Data for straight lines, R against S		Data for power functions			ΔS and S in ″/sec		Data for straight line $\bar{\sigma}$ R against	
	a	b	n	y-interc.	S_0	ΔS	S	a	b
Sit. 1									
8 a	14.0	0.59	3.19	27	—	16.6	25.4	6.1	0.1
6	13.8	0.54	0.38	—	11.25	12.5	29.0	10.8	−0.0
Sit. 2									
3 b	16.5	0.53	1.95	—	—	33.8	86.1	4.0	0.1
9	25.7	0.55	1.16	32	—	106.0	19.0	14.4	0.1
Sit. 3									
8 b	4.9	0.85	2.27	20	—	142.5	401.0	8.2	0.0
Sit. 4									
8 c	−18.9	1.37	1.66	0	—	—	—	3.8	0.1

4.7.2. *Analysis of data in connection with the problem formulated and criteria 1, 2 and 4 of perfect veridicality*

At beginning of point 4.6 (experimental section) the following problem was proposed: How does veridicality differ in judgments of speeds of other cars (V_B, V_C) in some selected traffic situations? (Situations 1–4.)

The reply can be given most simply by adapting criteria 1, 2 and 4 of perfect veridicality to data (magnitude estimation with standard).

Criterion 1 (linearity) does not discriminate the different situations. Deviation from linearity is characterized, with the exception of experiment 6 (V_C), by the function being positively accelerated. Situation 4 is similar in principle to the experimental situation commonly used in laboratory experiments on the judgment of velocity. The adaptation of the power function is good. The exponent ($n = 1.66$) is in good agreement with the result found in Ekman & Dahlbäck ($n = 1.72$).

Criterion 2 (R_z) does not discriminate the situations. With the exception of experiment 9, veridicality is rather good in all experiments. Deviation is very marked in experiment 9. This is most likely due to the fact that the stimulus information is so poor that great shifts in the R-continuum easily arise.

Criterion 4 (slope of the line) discriminates the situations very clearly into three groups. Very similar values were obtained in situations 1 and 2, with great deviations from perfect veridicality. The slope then increases with increased angle velocity and becomes most veridical in situation 3. Thus veridicality does not increase unambiguously with increased information since situation 4 gives greater deviation from perfect veridicality than situation 3. The fact that the same slope is obtained in situations 1 and 2 is most likely due to both situations giving limited and rather little information on V_B and V_C respectively. The table illustrating angle velocity (point 4.4) shows that the difference between situations 1 and 2 is small compared with the difference between these and situations 3 and 4.

4.7.3. *The differential threshold and the Weber ratio*

The calculations on which this analysis is based are described in points 4.4 and 4.5. Brown (1961) has, after analysing a large number of investigations of visual sensitivity to differences in velocity, shown that determinations of thresholds and the Weber

ratio have been used successfully in analyses of this field of perception. The analysis gave $\Delta S = 0.10$ S, but Brown stresses that it is to be expected that the ratios increase markedly at extremes of S. Brown's ratio is based on angle velocities which are usually much greater than mine. The values calculated for ΔS and S from all experiments except 8c have been plotted, which gave Fig. 4:18.

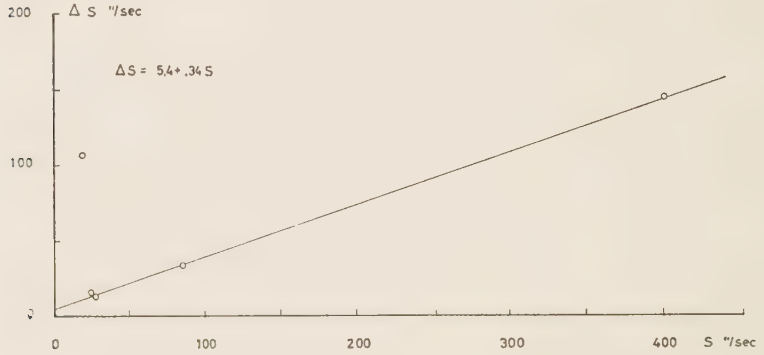

Fig. 4:18 ΔS plotted against S in "/sec.

The figure shows that, with the exception of experiment 9, there is a linear relation between ΔS and S, but that the Weber ratio has, as expected, a much higher value than Brown's. Brown (1961) shows in his summary that, in experiments on prediction of future position of a moving target, there is a great increase in mean errors (10 per cent to 25–53 per cent) at low angle velocities. The change occurred here for approximately 22 '/sec to ca. 11 '/sec. The latter angle velocity is equivalent to about the velocity arising at $V_B = 60$ km/h in experiment 8b.

Data from experiment 9 differ greatly from data from other experiments. There may be doubt as to how to calculate ΔS and S when data has such a lack of veridicality according to criterion 2. Even though other methods of calculation were used, e.g. that $S_{exp.\ 9} \cdots S_{exp.\ 3b}$, the discrimination error will be very great.

The increase in error is probably connected with the circumstance that the background and reference points become diffuse so that, for example, the lateral angle motion on the picture plane is not registered by the subject.

It is not unreasonable to assume, in the light of other data, that discrimination errors of similar size arise in the estimation of V_C with C's rear lights as stimuli under otherwise similar conditions.

4.7.4. *Relation between discriminal sensitivity on the subjective continuum and subjective magnitude*

The method of calculating $\bar{\sigma}_R$ is described under point 4.5. Detailed data will be found in the appendix. For a- and b-values see the table in point 4.7.1. The purpose of the calculations is to ascertain whether a linear relation is present for subjective variables, too, and to relate the results to the discussion of the division of perceptual continua into prothetic and metathetic continua (Stevens, 1957).

The plotting of $\bar{\sigma}_R$ against $\bar{R}$ (see figure and table above) gives consistently rather low b-values and rather high a-values. No unambiguous tendency over situations is present. For comparison, $\bar{\sigma}_R$ and R have been calculated for judgments of V_A (experiment 2 b).

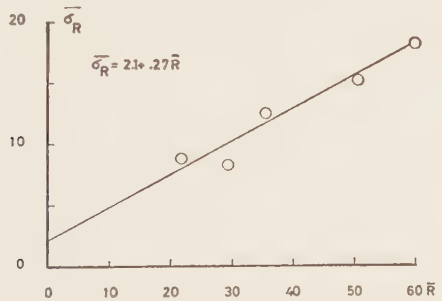

Fig. 4:19 $\bar{\sigma}_R$ plotted against $\bar{R}$ (experiment 2 b).

In this type of speed estimation a clear linear relation, with high b-values and low a-values, is obtained.

Stevens dichotomizes perceptual continua into two classes, prothetic and metathetic (Stevens, 1957). He mentions several criteria by which these two classes can be distinguished. The basic criterion is that for prothetic continua, Weber's law holds for subjective variables and thus in metathetic continua subjective variability does not vary with subjective magnitude. Since the a- and b-values vary between different experiments, since subjective range is relatively narrow, and as the stimuli lie close to the absolute threshold region the results must be interpreted with caution. It should be borne in mind, too, that at present there is lack of clarity regarding quantification in terms of, e.g., a- and b-values of protheticness (Eisler, 1963).

In view of the uncertainty of the data, the results have been interpreted as follows. Unambiguous metathetic tendencies are found in the data, e.g. experiments 3b and 6. From this there follows the hypothesis that subjects, when estimating V_B and V_C, have a tendency to consider position simultaneously instead of making more immediate judgments of speed. This hypothesis may probably be tested by a series of experiments in which both speed and distance are included as independent variables.

CHAPTER 5

SUMMARY

This experimental study is an independent part of a larger project. It is of an exploratory, general psychological nature, and is restricted mainly to driver behaviour in the input phase of a meeting situation.

Chapter 1 gives a brief survey of scientific behavioural traffic research. The need for, among other things, experimental research in the input region, and the difficulties to obtain scientifically acceptable measures of a driver's behaviour in traffic are mentioned. The experimental situation chosen, which consists of a track, 700 m long, along which two cars are driven, either in opposite directions or after each other, is described. The task set the subjects was to assess simultaneously the speeds of the two cars.

The choice of method is discussed and reasons are given for the choice of direct scaling methods. The term "veridicality" is introduced as a designation of the agreement between subjective and physical variables. It is defined operationally with a system of four criteria, linearity, R for standard, y-intercept and slope of line.

Chapter 2 contains an account of experiments on the judgment of the speed of own car (V_A), the speed of an oncoming car (V_B), and that of a car driving in front of and in the same direction as own car (V_C).

The results of each experiment are reported with a function for R against S. A straight line and, in most cases, a power function are fitted to data. The results are analysed as devia-

tions from perfect veridicality according to the respective criteria. A table at the end of the chapter gives a summary of the partial experiments and their results.

Deviation from linearity, criterion 1, is present in most experiments. It is manifested as a positively accelerating tendency in experiments on V_A and V_B, and as a negatively accelerating tendency in experiments on V_C. The deviations within the experimental range are however small. The R-value for standard, criterion 2, has rather good average agreement, with a slight tendency to underestimation. The obvious exception is experiment 5b on estimation in km/h and 0 speed of V_A and V_B, which gives underestimation. The deviation of the y-intercept from 0 (criterion 3) is very great in experiments on V_B and V_C. The slope of the fitted straight line (criterion 4) deviates very little from 1 in the V_A experiments. On the other hand, deviation is great in the V_B and V_C experiments.

Agreement between results obtained by different methods is good. Ratio and magnitude estimations give results that are very similar to each other. The same applies to estimations of distance driven and speeds in km/h. To sum up it may be said that the ability of subjects to judge the speed of own car (V_A) is good, while ability to estimate the speeds of an oncoming car (V_B) and one driving in front of and in the same direction as own car (V_C) is greatly inferior. These results are valid for the experimental situation used.

Chapter 3 contains a combination of data from predictive judgments of meeting point between cars A and B (Björkman, 1963) with my own data for the separate subjective variables (v_A, v_B and d) included in the predictive judgments. The systematic errors in the prediction of meeting point may be assumed to be due to lack of veridicality in the judgments of the individual situation variables, V_A, V_B and D, and on the lack of ability on

the part of the subjects to organize and combine information on these variables in the prediction.

The combination of data shows that prediction of meeting point is made without any regard whatever to the experienced differences in speed. This means that the subjects have been unable to make use of the items of information obtained in the simultaneous judgment in the more complicated meeting situation. This result is in agreement with the findings of laboratory experiments on the prediction of collision made by Gottsdanker and Edwards (1957), whose results indicate that for accelerated and constant-speed targets the prediction was based on relative positions at the time when the targets disappeared rather than on relative speeds or accelerations.

Chapter 4 gives an account of an experimental study of judgments of V_B and V_C. Four representative traffic situations were chosen, with different distances between the lanes. In situation 1 the cars drove along the same lane; in situation 2 they drove along separate lanes at a lateral distance of 5 m from each other; in situation 3 the cars drove along separate lanes at a lateral distance of 25 m from each other; in situation 4 they drove along separate lanes, which crossed each other at right angles. This arrangement makes it possible to use data from some of the experiments reported in Chapter 2. Thus situation 1 includes experiment 6, magnitude estimation of V_C, and situation 2 includes experiment 3b, magnitude estimation of V_B. The new experiments are magnitude estimation of V_B (situations 1, 3, 4) and magnitude estimation of V_B in night driving (situation 2).

In the processing of the data, S is described in km/h in each situation, and in changes of angle of vision (″/sec.). The latter give a common measure for the different situations, which can also be used in comparisons of data obtained in laboratory experiments on visual perception of velocity.

Data obtained in each experiment are described by means of a R–S function. The result can then be related to the criteria of veridicality cf. (Chapter 2.). In addition, the data have been treated as threshold data in the method of constant stimuli. Since the standard ($V_A = 40$ km/h) is in the middle of the S distribution, the judgments can be divided into the categories "smaller than", "same as" and "greater than". After a proportional division of "same as", "greater than" has been used for the calculation of the z-values. In this way, S and ΔS were obtained in ″/sec for each experiment. Finally, the corresponding values for subjective variables $\bar{\sigma}_R$ and $\bar{R}$ have been calculated.

The analysis of data from the starting-point of the criteria of veridicality gives the following results. Deviation from linearity (criterion 1) has the same tendency over situations. Except for experiment 6 (V_C), $n > 1$ was obtained for the power functions. R for standard (criterion 2) shows rather good agreement with the veridical value. Experiment 9 is a clear exception, for great overestimation occurs there.

Deviation from perfect veridicality according to criterion 4 ($b = 1$) is clear. The experiments in situations 1 and 2 show the same great deviations, after which the slope of the line increases with increasing angle velocity to $b = 1.37$ in situation 4.

ΔS and S in ″/sec from the experiments in situations 1–3 have been plotted against each other. A linear relation with the equation $\Delta S = 0.34\ S + 5.4$ was obtained. Weber's law has been shown to be valid for data from laboratory experiments on discrimination of differences in speed (Brown 1961). An average constant of 0.10 has been obtained for these data referring to higher angle velocities. At extremely low values of angle velocity, such as we are concerned with here, it is reasonable to expect a great increase in the constant. Data from experiment 9 (night

driving) deviate very much from the other data, and fall far from the fitted line. ΔS assumes a very high value in relation to S, which shows that discrimination of V_B is very faulty in this night-driving situation.

Plotting $\bar{\sigma}_R$ against R for each experiment gives rather varying values of b and a in the adapted straight lines. The slopes are rather low on an average, however, which suggests a tendency to constancy in $\bar{\sigma}_R$. This tendency may in its turn be connected with the distinction prothetic-metathetic continua (Stevens, 1957). The main criterion for this distinction is that $\bar{\sigma}_R$ is constant for extremely metathetic continua. The data obtained may therefore serve as a starting-point for the hypothesis that the subjects are more inclined to choose position rather than make a more direct judgment of speed.

APPENDIX

Chapter 2: *Experimental studies of judgment of speed in a meeting situation*

Experiments on judgments of speed and distance driven of own car

Experiment 1 a. Ratio estimation of V_A

1. Group scale

S	R
20	22.2
30	26.6
40	35.4
50	49.6
60	62.6

2. Ratios from ratio estimation

		V_B				
		60	50	40	30	20
V_A	60	1.33	1.34	1.49	1.95	2.00
	50	0.869	1.03	1.34	1.59	1.91
	40	0.636	0.722	0.832	1.14	1.31
	30	0.536	0.497	0.631	0.712	0.878
	20	0.421	0.478	0.525	0.704	0.713

Experiment 2 a. Magnitude estimation of V_A

1. Individual scales (R-values for subjects 1–3). 2. Group scale

S	1	2	3	S	R
20	15.1	31.6	26.2	20	23.2
30	28.5	36.7	29.4	30	31.4
40	39.8	40.9	39.2	40	39.9
50	58.8	46.0	57.0	50	53.6
60	71.9	51.1	71.9	60	64.2

Experiment 2 b. Magnitude estimation of V_A

1. Individual scales (R-values for subjects 1–11).

S	1	2	3	4	5	6	7	8	9	10	11
20	26.2	20.7	13.8	13.2	14.3	10.1	15.8	18.7	30.6	37.4	18.4
30	38.0	27.4	26.0	28.1	21.1	24.2	23.8	25.3	34.7	34.8	26.6
40	45.1	34.6	38.6	39.3	30.2	25.5	33.0	35.0	39.3	35.1	30.6
50	54.7	40.6	49.0	45.0	50.5	44.3	49.1	43.3	59.5	46.7	48.0
60	62.8	45.2	52.5	53.3	59.2	51.9	62.6	57.4	77.2	51.4	57.6

2. Group scale

S	R
20	16.0
30	27.9
40	34.7
50	48.0
60	56.8

3. p- and z-values

S	p	z
20	1	− 2.33
30	8	− 1.41
40	22	− 0.77
50	86	+ 1.08
60	94	+ 1.55

4. $\bar{R}$ and $\bar{\sigma}_R$

S	$\bar{R}$	$\bar{\sigma}_R$
20	21.7	8.7
30	29.4	8.3
40	36.6	12.5
50	50.2	15.2
60	60.0	18.2

Experiment 5 a. Judgment of D_A

1. Matrix of d_A

		V_B					
		0	20	30	40	50	60
V_A	0	0	0	0	0	0	0
	20	24.1	21.0	21.7	20.4	21.1	20.5
	30	33.6	34.5	36.4	36.7	34.0	33.3
	40	56.3	53.6	51.8	56.8	50.1	46.8
	50	61.5	70.9	70.5	72.1	66.1	77.8
	60	107.8	91.7	97.8	94.0	105.2	96.3

2. Average group scale

S	R
0	0
27.5	21.4
41.5	34.7
55.5	52.4
69.0	69.6
83.5	98.6

Experiments on judgments of speed and distance driven of oncoming car

Experiment 1 b. Ratio estimation of V_B

For ratio matrix see experiment 1 a.

1. Group scale

S	R
20	29.9
30	32.8
40	40.0
50	48.0
60	51.4

Experiment 3 a. Magnitude estimation of V_B

1. Individual scales(R-values for subjects 1–5).

S	1	2	3	4	5
20	33.0	29.6	34.7	39.4	32.4
30	36.6	33.7	38.2	40.2	41.5
40	38.8	37.4	37.2	36.5	47.4
50	46.6	43.4	44.2	50.2	50.9
60	55.3	46.8	47.8	57.7	51.3

2. Group scale

S	R
20	33.7
30	37.9
40	39.2
50	47.0
60	51.6

Experiment 3 b. Magnitude estimation of V_B

1. Individual scales (R-values for subjects 1–7).

S	1	2	3	4	5	6	7
20	34.6	35.0	31.5	24.7	30.9	29.5	18.2
30	39.4	37.0	28.3	33.7	35.8	32.5	16.5
40	50.1	36.8	39.6	34.6	36.0	32.7	29.0
50	62.2	51.7	46.2	45.4	43.0	40.1	24.2
60	62.8	63.4	48.3	44.0	52.4	41.6	35.9

2. Group scale

S	R
20	28.6
30	30.9
40	36.5
50	43.2
60	48.8

3. p- and z-values

S	p	z
20	6	−1.55
30	22	−0.77
40	47	−0.08
50	77	+0.74
60	85	+1.04

4. $\overline{R}$ and $\overline{\sigma}_R$

S	$\overline{R}$	σ_R
20	31.2	7.9
30	34.2	11.5
40	39.0	11.4
50	47.2	13.2
60	52.1	12.3

Experiment 4. Judgment of V_B in km/h

1. Matrix of v_B

		V_B					
		0	20	30	40	50	60
V_A	0	1.7	9.8	34.7	36.3	44.8	42.4
	20	2.4	15.1	19.5	30.9	37.0	40.6
	30	4.6	18.6	17.6	36.7	38.9	43.6
	40	3.0	15.0	20.3	28.4	36.3	46.2
	50	4.1	15.7	21.2	31.3	42.6	41.6
	60	4.6	14.3	15.9	30.6	38.2	51.2

2. Average group scale

S	R
0	3.2
20	14.8
30	20.8
40	32.2
50	39.5
60	44.1

Experiment 5b. Judgment of D_B

1. Matrix of d_B

		V_B					
		0	20	30	40	50	60
V_A	0	1.77	24.7	13.0	40.2	45.6	55.4
	20	3.49	10.7	17.5	23.1	54.9	50.7
	30	5.36	13.5	26.6	34.3	68.7	56.7
	40	7.77	14.7	10.4	44.0	53.3	59.8
	50	10.30	25.6	22.2	44.7	68.2	55.5
	60	4.11	21.9	28.8	35.1	68.2	75.6

2. Average group scale

S	R
0	4.7
27.5	17.6
41.5	18.5
55.5	36.1
69.0	59.1
83.5	58.5

Experiments on judgment of speed of car driving in front of and in the same direction as own car

Experiment 6. Magnitude estimation of V_C

1. Individual scales (R-values for subjects 1–12).

S	1	2	3	4	5	6	7	8	9	10	11	12
20	22.4	28.3	21.4	25.9	24.9	20.6	29.2	32.1	23.9	20.6	21.1	18.3
30	29.4	29.0	34.9	29.8	33.9	31.0	30.7	38.2	21.8	20.4	31.4	27.9
40	38.5	33.5	38.0	42.4	37.0	36.6	40.0	38.2	33.6	40.9	37.4	30.3
50	41.0	39.7	44.4	42.2	53.4	38.3	43.8	47.8	39.6	43.9	41.2	33.3
60	44.8	43.0	48.1	52.6	51.7	37.1	43.2	48.2	37.8	49.5	50.6	39.5

2. Group scale		3. p- and z-values			4. $\bar{R}$ and $\bar{\sigma}_R$		
S	R	S	p	z	S	R	$\bar{\sigma}_R$
20	23.8	20	6	−1.55	20	26.0	9.5
30	30.0	30	20	−0.84	30	31.8	10.5
40	37.0	40	56	+0.15	40	38.6	10.7
50	41.6	50	60	+0.25	50	43.0	9.3
60	45.2	60	81	+0.88	60	46.6	9.3

Experiment 7. Judgment of V_C in km/h

1. Average group scale for standards 30 and 50		2. Group scale with standard 30 km/h		3. Group scale with standard 50 km/h	
S	R	S	R	S	R
0	21.2	0	20.3	0	22.0
20	24.9	20	26.1	20	23.7
30	33.0	30	32.0	30	34.0
40	37.4	40	34.2	40	40.6
50	39.3	50	37.0	50	41.6
60	43.7	60	44.0	60	43.4

CHAPTER 3: *Combination of data from predictive judgments of meeting point with data from judgments of speeds and distances*

1. q_{AB} from ratio estimation (experiment 1) see experiment 1.

2. q_{AB} from judgment of distance driven (experiment 5)

		V_B				
		60	50	40	30	20
V_A	60	1.25	1.55	2.69	3.38	4.18
	50	1.39	0.97	1.60	3.22	2.73
	40	0.78	0.94	1.30	5.20	3.60
	30	0.58	0.49	1.09	1.33	2.40
	20	0.41	0.38	0.85	1.22	1.91

3. Q_{AB}, objective ratios

	60	50	40	30	20
60	1.00	1.20	1.50	2.0	3.0
50	0.83	1.00	1.25	1.67	2.5
40	0.67	0.80	1.00	1.33	2.0
30	0.50	0.60	0.75	1.00	1.50
20	0.33	0.40	0.50	0.67	1.00

4. D_A/D_B from Björkman's data

	60	50	40	30	20
60	1.12	1.18	1.15	1.21	1.17
50	0.96	0.98	1.03	1.05	1.09
40	0.92	0.91	0.99	1.07	1.00
30	0.82	1.02	0.78	0.95	0.90
20	1.31	1.08	0.85	1.00	0.93

Chapter 4. *Judgments of speed of oncoming car and of car driven in front of and in the same direction as own car (V_B, V_C) with variations of lateral distance.*

Experiment 8a. Magnitude estimation of V_B

1. Individual scales (R-values for subjects 1–13).

S	1	2	3	4	5	6	7	8	9	10	11	12	13
20	39.3	21.8	22.6	10.9	31.2	39.2	19.8	21.0	29.2	34.3	32.1	36.6	41.4
30	32.7	23.8	28.2	28.6	33.9	41.1	25.5	14.7	26.0	31.2	32.3	36.2	42.1
40	41.0	26.9	35.4	44.2	36.8	42.2	34.2	20.7	45.1	39.3	50.2	41.6	37.0
50	46.0	29.0	28.9	38.1	46.3	44.7	50.8	36.6	44.0	49.9	52.1	47.4	43.8
60	43.9	39.0	38.7	46.7	54.8	54.2	53.5	52.6	60.6	53.8	54.1	51.1	48.8

2. Group scale

S	R
20	25.3
30	31.4
40	39.1
50	42.2
60	49.2

3. p- and z-values

S	p	z
20	24	−0.71
30	34	−0.41
40	46	−0.10
50	67	+0.44
60	83	+0.95

4. $\overline{R}$ and $\overline{\sigma}_R$

S	$\overline{R}$	$\overline{\sigma}_R$
20	31.6	10.4
30	33.3	11.9
40	40.5	12.7
50	45.6	14.6
60	51.4	13.5

Experiment 8b. Magnitude estimation of V_B

1. Individual scales (R-values for subjects 1–8).

S	1	2	3	4	5	6	7	8
20	27.5	10.2	23.4	17.4	19.8	25.1	38.8	36.2
30	34.4	13.8	36.8	26.6	21.6	31.2	46.9	31.6
40	43.0	28.4	53.8	33.0	33.4	39.8	47.3	44.6
50	48.3	43.6	57.0	35.9	42.7	41.1	49.0	43.4
60	61.3	52.2	79.0	43.4	54.6	55.4	60.6	57.1

2. Group scale

S	R
20	23.0
30	28.7
40	39.6
50	44.8
60	57.2

3. p- and z-values

S	p	z
20	10	−1.28
30	14	−1.08
40	56	+0.15
50	76	+0.71
60	96	+1.75

4. $\overline{R}$ and $\overline{\sigma}_R$

S	R	$\overline{\sigma}_R$
20	26.6	8.8
30	31.9	9.1
40	41.6	9.5
50	46.0	9.2
60	58.6	9.7

Experiment 8c. Magnitude estimation of V_B

1. Individual scales (R-values for subjects 1–11).

S	1	2	3	4	5	6	7	8	9	10	11
20	5.3	13.9	8.2	14.8	7.5	14.2	14.3	6.6	14.1	16.9	8.5
30	10.7	25.7	18.6	23.0	18.7	29.8	25.0	18.2	24.8	25.0	16.0
40	34.6	39.7	31.4	33.6	30.2	39.1	38.5	37.8	36.8	38.4	29.0
50	48.5	53.4	44.4	44.6	46.6	52.8	45.5	43.4	51.3	50.9	48.9
60	67.5	83.1	54.8	66.4	58.3	70.0	60.6	57.0	70.7	64.8	73.6

2. Group scale

S	R
20	10.6
30	20.8
40	35.2
50	48.1
60	65.6

3. p- and z-values

S	p	z
20	0	∞
30	0	∞
40	23	-0.74
50	90	$+1.28$
60	100	∞

4. $\bar{R}$ and $\bar{\sigma}_R$

S	R	$\bar{\sigma}_R$
20	12.4	5.0
30	23.5	8.7
40	36.2	7.4
50	49.1	10.4
60	67.2	13.4

Experiment 9. Magnitude estimation of V_B in the dark with dipped headlights on both cars

1. Individual scales (R-values for subjects 1–10).

S	1	2	3	4	5	6	7	8	9	10
20	48.6	40.9	40.0	47.5	50.4	13.4	56.6	39.4	41.8	40.3
30	36.5	41.0	46.7	54.9	44.4	13.8	40.3	38.4	45.5	45.5
40	43.0	41.9	47.9	53.8	62.6	47.0	46.5	41.4	43.0	45.0
50	53.9	46.4	54.7	58.2	52.5	63.7	61.4	48.0	47.2	49.1
60	60.2	44.6	49.4	77.5	90.2	51.2	87.3	53.2	59.4	46.3

2. Group scale		3. p- and z-values			4. $\bar{R}$ and $\bar{\sigma}_R$		
S	R	S	p	z	S	R	$\bar{\sigma}_R$
20	39.7	20	63	+ .33	20	47.4	22.3
30	38.7	30	65	+ .39	30	47.2	19.4
40	46.9	40	73	+ .61	40	53.3	24.9
50	53.2	50	83	+ .95	50	60.0	24.9
60	60.0	60	91	+1.34	60	65.4	23.0

Method of calculating power functions

1. Geometric means of R were plotted against S.

2. A power function was fitted by ocular inspection to obtain an approximate y-intercept (b).

3. Log(R-b) were plotted against log S for a series of b-values starting from nearest whole number below the approximate y-intercept. The intervals between the b-values of the series were 0.1 on the arithmetic R-scale.

4. The b-value giving the best linearity by ocular inspection was chosen.

5. The parameters c and n of the power functions were determined as A and B for the best fitting straight line according to a least squares criterion for the data from point 4.

6. The R-scale and the constants b and c of the power functions were transformed by multiplying the values by 0.8.

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